REGIONAL CLASSIFICATION OF TASMANIAN COASTAL WATERS

AND PRELIMINARY IDENTIFICATION OF REPRESENTATIVE MARINE PROTECTED AREA SITES

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From:
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EXECUTIVE SUMMARY

Analysis of the distribution of reef plants and animals at over 150 sites around the Tasmanian coastline and Bass Strait islands indicated that Bass Strait reef communities were distinctly different from those occurring further south. This major division in reef ecosystems reflected a boundary near Cape Grim and Little Musselroe Bay between two biogeographical provinces. Each of the two bioprovinces was divisible into four biogeographical regions (bioregions), which occurred along the northern Tasmanian coast and at the Kent Group, Furneaux Group and King Island in Bass Strait, and along the northeastern, southeastern, southern and western coasts of Tasmania. In contrast to these patterns identified using data on coastal reef communities, regional classifications for estuarine and soft-sediment faunas (based on the distribution of beach-washed shells and beach-seined fishes) were less clearly defined.

In order to manage and protect Tasmanian inshore plants and animals in accordance with the principle of ecologically sustainable development, an integrated system of representative marine protected areas is considered a necessary adjunct to appropriate regulations concerning individual marine species. The benefits of a marine reserve system include (i) the provision of fish propagation areas, (ii) insurance against the possibility of fishery stock collapses, (iii) the formation of areas where natural ecosystem processes can be scientifically investigated, (iv) the maintenance of reservoirs of genetic diversity, (v) the provision of recreational sites for divers and naturalists, and (vi) areas of focus for public education about coastal life.

An integrated Tasmanian system of marine protected areas should include at least one area within each bioregion extending for ≈10 km of coast where plants and animals are protected from exploitation. The recommended locations where representative marine reserves should be declared are Maria Island, Port Arthur or Tinderbox, Port Davey, Sloop Rocks or Point Hibbs, New Year Islands (King Island), the Kent Group, western Franklin Sound (Flinders Island), Rocky Cape and Macquarie Island. Because no Tasmanian marine reserve presently exists within the Bassian bioprovince, the immediate priority is to declare a marine reserve in the Bass Strait region. The species diversity protected within Tasmanian marine reserves will be maximised if that reserve is located in the vicinity of Deal Island.

The identification and declaration of estuarine protected areas was not considered in the present report but should also be addressed as a matter of urgency.

INTRODUCTION

Ecologically sustainable development of coastal ecosystems is now generally recognised to involve more than the management of individual species and non-biological resources, because the exploitation of one resource will have flow on effects to others. Given that many of the consequences of exploitation of particular animal and plant species are unpredictable, the declaration of an integrated system of representative marine protected areas is recommended as an important coastal management practice alongside appropriate regulations concerning individual marine species (Zann, 1995).

The benefits of a marine reserve system include virtually all advantages accruing from a terrestrial national park system, with the additional benefit that the larval stage that is characteristic of most marine species disperses to sites at great distance from the protected parents. Moreover, the distribution and taxonomy of marine species is poorly known compared to terrestrial species so single species management is more difficult and habitat protection more desirable when dealing with coastal systems. Benefits gained from an integrated system of marine reserves include:

(i) the provision of fish propagation areas. The major functional difference between marine and terrestrial ecosystems is the greater mobility of animals in the sea and the high level of biotic connectivity between distant communities (Fairweather and McNeill, 1993). The release and long distance dispersal of reproductive propagules generated by high densities of fishery species within protected areas therefore enhances recruitment at distant sites.

(ii) insurance against the possibility of fishery stock collapses. Very little is known about the ecology of marine organisms and how they will react to sustained exploitation, so it is sensible to take precautions against fishery stock crashes by maintaining reserves of brood stock (Ballantine, 1991).

(iii) protection of areas where natural ecosystem processes can be scientifically investigated. Without the availability of marine reserves as control areas, the effects of exploitation on marine communities cannot be determined. Marine reserves also often provide the best conditions for scientific research because fishery species are present in high numbers, minimising sampling effort, and because experimental work is less likely to be disrupted or interfered with (Berry, 1993).

(iv) maintenance of reservoirs of genetic diversity. Virtually all studies on the effects of marine reserves show that increases in the diversity of fish occur (Fairweather and McNeill, 1993), and the diversity of other organisms presumably also increases in protected areas. Because of the lack of knowledge about the distribution and taxonomy of marine organisms, the declaration of a representative system of marine reserves is considered the best way to minimise loss of species in coastal ecosystems (Jones and Kaly, 1995). A number of ethical arguments can be made for conserving biodiversity (Ehrlich and Ehrlich, 1981), while it is also economically sensible to prevent extinction of marine organisms, given the potential biotechnological value of chemical compounds produced by unscreened marine species for use as antibiotics, anticancer pharmaceuticals, glues, antifouling agents, etc. (Heyward, 1994)

(v) provide recreational sites for divers and naturalists. Protection of the biota within marine reserves provides a biological and aesthetic attraction to divers and naturalists, in the same way that bushwalkers and other visitors are attracted to terrestrial nature reserves. The number of qualified SCUBA divers in Australia is large (≈700,00) and believed to be growing at ≈25% per year (LCC, 1995), hence this recreational benefit of marine reserves is highly significant.

(vi) act as foci for public education about coastal life. Education is generally regarded as one of the most important management tools. Cost effective management of coastal resources should therefore include an education program where the public can learn about the value of the marine environment, the threats to it, and the skills to look after it (Zann, 1995). Marine reserves are important components of such education programs because their presence helps to instil conservation values on the public (Pollard, 1977), and coastal management information can be distributed in a non-intrusive way using signage and, in some cases, nearby interpretation centres.

Until the 1970s, little thought was given to the integrated management of Tasmanian marine ecosystems because coastal waters were widely considered an open-ended source of fish production and sink for the dumping of sewage and industrial waste. However, at that time a number of problems emerged that clearly indicated severe degradation of the marine environment, at least in localised areas. These problems included declining catches of commercial fish species despite increasing effort (Harrison, 1975) and gross contamination of estuarine shellfish and fish by heavy metals (Dix et al., 1975; Bloom and Ayling, 1977). Government agencies then acted to remedy these problems by placing greater controls on fish catches, sewage discharge and the dumping of mineral waste. The National Parks and Wildlife Service (NPWS) and Tasmanian Fisheries Development Authority (TFDA) also recognised at that time that a system of representative marine reserves was needed in order to protect marine plants and animals for conservation and fish propagation purposes (Kriwoken and Haward, 1991).

The most critical information needed when optimising the conservation value of a marine reserve system is data on the distribution of the biota, so as to avoid unnnecessary duplication of protected areas that conserve one community type while leaving others unprotected. Accordingly, NPWS and TFDA commissioned surveys of the biota at various sites around the coastline in 1980 and 1983 which were aimed at (i) determining the number and extent of the major biotic regions around Tasmania, and (ii) identifying the most appropriate location for at least one representative reserve within each of these biotic regions. In order to maximise the time spent undertaking these surveys, the majority of sites investigated were adjacent to terrestrial National Parks and Nature Reserves. If other factors are equal, a marine reserve that is located adjacent to a terrestrial protected area should be substantially superior to one adjacent to private land because of (i) greater control over anthropogenic impacts within the water shed that impinge on the coastal ecosystem, (ii) fewer policing difficulties because of the proximity of National Parks and Wildlife Service staff, and (iii) greater isolation, so fishing restrictions would have less impact on existing recreational fishers.

The results of these surveys, with consideration of the social and economic effects of fishing and other restrictions at proposed sites, were published as two reports (Edgar, 1981,1984). Three marine provinces were recognised to overlap within the Tasmanian region, with the following representative marine reserves recommended as the most suitable locations within each of these provinces:

1. Maria Island. The coastal habitat off northeastern and northern Maria Island on Tasmania’s central east coast was recommended as it is representative of the Maugean Marine Province (Tasmania south of Bass Strait, Bennett and Pope, 1964), has a very high species diversity, an extremely wide range of habitats within a small area (rock, sand, seagrass, kelp forest, and dolerite, siltstone, sandstone, granite and limestone reef habitats), a relatively low usage by recreational fishers, and is adjacent to an existing terrestrial National Park.

2. Rocky Cape. The coastal habitat between Boat Harbour and Rocky Cape in Tasmania's northwest was recommended as it is representative of the Flindersian Marine Province (southern Western Australia to Bass Strait), has a very high fish diversity, a great geomorphological diversity, is the only extensive reef system on the northwestern Tasmanian coast that has not been severely degraded by pollution and fishing, and is offshore from an existing National Park.

3. The Kent Group. The coastal habitat surrounding the Kent Group of islands in northeastern Bass Strait was recommended as this area is locally influenced by the East Australian current, has a large component of species that are typical of the Peronian (NSW) Marine Province, a diverse fish fauna, a range of reef, sand and seagrass habitats off sheltered to submaximally exposed shores, and is little affected by fishing or pollution.

A further three small marine reserves in eastern Tasmania were also recommended to protect the biota at two popular recreational diving locations (Tinderbox, Governor Island) and to preserve a unique habitat at Ninepin Point.

Because of a lack of political will and the vocal opposition of some fishers, the recommendations were not acted on until 1989 (Kriwoken and Haward, 1991), with the three small marine reserves and a substantially-diminished Maria Island reserve declared in 1991. Although the merits of the Rocky Cape and Kent Group marine reserve proposals were recognised by the Working Group that coordinated the declaration of the 1991 marine reserves, these two reserves were considered a second stage that would be acted on once the first stage reserves were successfully established. This has not yet been done.

Since 1990, an additional representative marine reserve has been considered at subantarctic Macquarie Island (see Scott, 1994), and the recent nomination of Macquarie Island as a World Heritage Area included a proposal for a marine reserve extending three nautical miles offshore (Kriwoken, 1993). The Insulantarctic Marine Province, which includes Macquarie Island, was outside the areas considered during the original Tasmanian survey work (Edgar, 1984).

Considerable investigative work has been undertaken recently within Tasmanian waters, largely as a consequence of funding provided by the Australian Government under the Ocean Rescue 2000 program that is aimed a facilitating the declaration of a network of marine protected areas around Australia. This assistance has been used in Tasmania to conduct biological surveys with the following aims:

* to assess the impact of existing marine reserves on reef biota
* to provide baseline data on the abundance of plants and animals at potential marine reserve sites
* to provide baseline data on the abundance of plants and animals around Tasmania that can be used to monitor the long-term effects on marine ecosystems of climate change, species introductions, overfishing, etc.
* to identify any new or alternative sites that should be included in a proposed marine reserve system
* to refine the regionalisation of Tasmanian coastal habitats

In this report, quantitative data on reef communities collected between 1992 and 1994 are compared with information on sea surface temperature, the distribution of beach-washed shells and the distribution of fishes in shallow soft-sediment habitats, to determine a biological regionalisation of Tasmanian coastal waters. The most appropriate sites that should be protected within a representative marine reserve system are identified on the basis of available data. The approach used here to delineate regions differs from that used in most other marine bioregionalisation studies because of the emphasis on analysis of systematically collected biological data. Bioregions are more often identified by subjective means using panels of experts (the "Delphic" approach; see, e.g. Marine Parks and Reserves Selection Working Group, 1994), or by delineating habitat types using physical surrogates that can be remotely sensed over large areas (Belbin, 1993; Hamilton, 1994).

By providing a rational basis for a marine reserve system it is hoped that problems associated with the more usual pragmatic arrangement of declaring networks of *ad hoc* reserves will be avoided (see Margules et al., 1988; Ballantine, 1991; Ray and McCormick Ray, 1992; McNeill, 1994). The recommendations described here should be publicised widely amongst interested parties, including commercial and recreational fishers and divers, to allow public comment and possible amendment (Kriwoken and Haward, 1991).

PROJECT AIMS

* To finalise a regional classification of Tasmanian coastal waters which is consistent with and complements regional classifications being undertaken in other States and the Commonwealth.

*To utilise this regionalisation to review the Tasmanian Marine Protected Areas strategy.

* To make relevant information available in a standard format to assist with national marine information needs.

METHODS

DATA SETS

Tasmanian coastal habitats were subdivided into regions by analysing different biological and physical data sets, and then regional boundaries identified for each set were compared to determine congruent patterns. Data sets used during the study are described below.

Reef biota

Quantitative censuses of reef plants and animals were undertaken at 156 sites around the Tasmanian coast between 1992 and 1994 (Fig. 1; Appendix 1). Five anomalous sites located within an estuary (Bathurst Channel in southwestern Tasmania) were excluded from analyses due to extremely low fish and plant species richness and a relatively high cover of sessile invertebrates. Four other sites were censused for large fishes only.

At each reef site examined, the abundance of large fishes, the abundance of cryptic fishes and benthic invertebrates, and the percentage cover of macroalgae were each censused separately using visual transect methods. The densities of large fishes were estimated by laying four 50 m transect lines along either the 5m or 10 m depth contour and recording on waterproof paper the number of fish observed by a diver while swimming along the centre of a 5m wide swathe up one side and then down the other side of the line. A total of 4 x 500 m^2 transects was thus censused for large fish at each site.

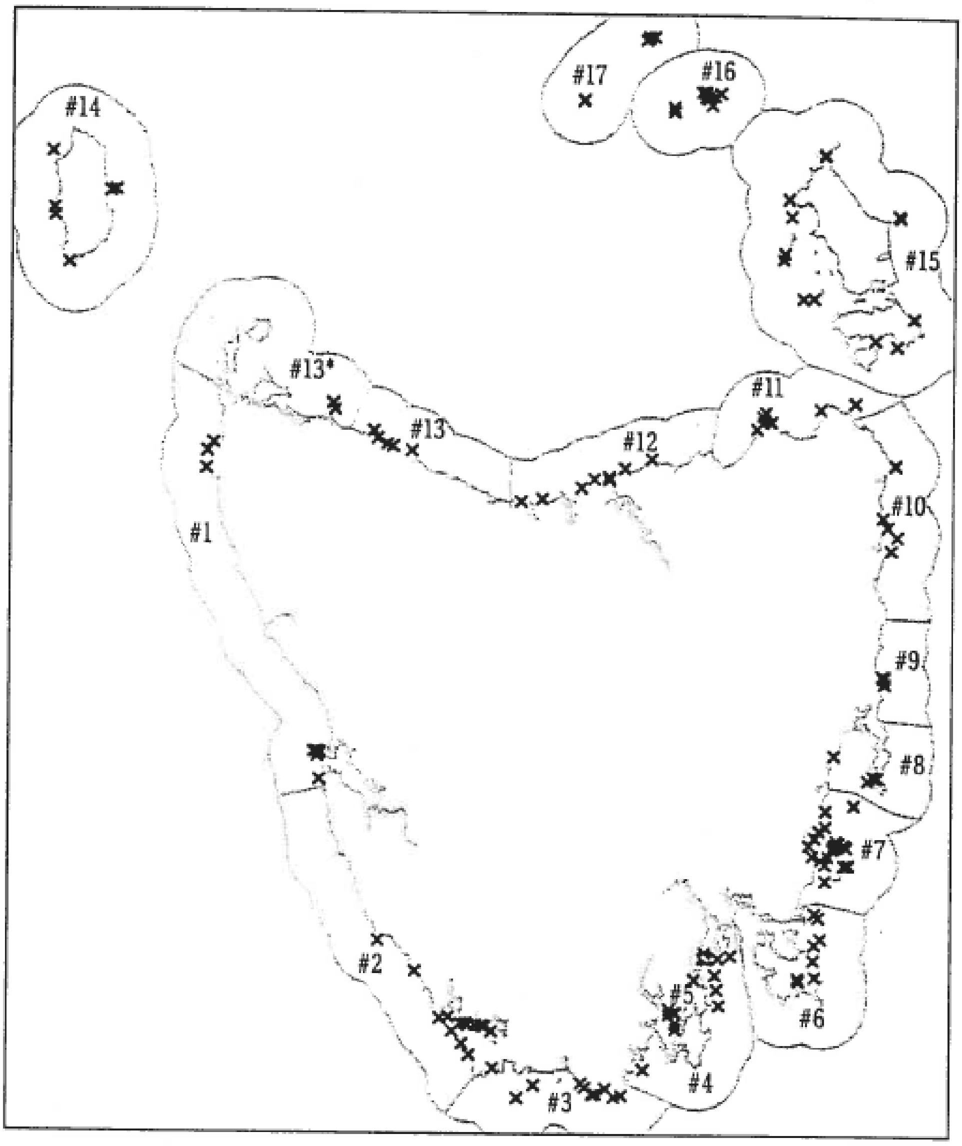

Fig. 1. Locations of reef sites around Tasmania at which plants, macroinvertebrates and fishes have been censused. The locations of the 17 zones into which the Tasmania coastline was initially subdivided are also shown. Zone 13 was separated into two subzones (13 and 13*) in shell and beach fish analyses.

Smaller fishes and megafaunal invertebrates (large molluscs, echinoderms, crustaceans) were next counted along the transect lines used for the fish survey by recording animals within 1 m of one side of the line (a total of 4 x 50 m^2 transects). The distance of 1 m was assessed using a 1 m stick carried by the diver. The percentage cover of macroalgal species was then determined by placing 0.5 x 0.5 m^2 quadrats at 10 m intervals along the transect line, and determining the percentage cover of the various plant species.

Quantitative information was reduced to presence/absence data for analysis here, with a total of 103 fish, 50 invertebrate and 108 plant taxa recorded during surveys at the 151 sites. However, as transects were undertaken by visual means, some doubt was associated with the identification of particular taxa. For example, the two Australian salmon species *Arripis trutta* and *Arripis truttacea* are best separated by gill raker counts and could not be distinguished by external appearance. Consequently, 4 fish, 6 invertebrate and 21 plant taxa were excluded from analyses because of unacceptable uncertainty about identifications.

Beached-washed shells

A Tasmanian naturalist, Margaret Richmond, has recorded the distribution of beach-washed shells at ≈350 sites around the Tasmanian coastline, including numerous Bass Strait islands. She kindly made her presence/absence data relating to 544 species of molluscs available for analysis here.

Beach-seined fishes

Presence/absence information on the distribution of 105 species of fishes collected by seine off Tasmanian estuarine and coastal beaches was obtained from Dr Peter Last; this information is contained in an appendix to his Ph.D. thesis (Last, 1983).

Sea surface temperatures

Water temperature data measured by NOAA satellite at 1 km^2 pixel resolution (100 pixels per degree of latitude) were obtained from CSIRO Division of Oceanography. Data were obtained in the late afternoon (1500 to 1700 hr) during cloud free days in February and July of each year between 1989 and 1992. Outlying data points were removed.

Bathymetry

Hydrographic charts were mapped at 10 m or 20 m intervals onto the GIS program MAPINFO for analysis of underwater topographic features (seabed slope, aspect, etc.).

These data did not add substantially to the regionalisation analysis and are not discussed here.

ANALYTICAL METHODS

Multidimensional scaling of biotic data

Ordination of reef data was carried out using multidimensional scaling (MDS) on either the PRIMER statistical package provided by the Plymouth Marine Laboratories or the PATN statistical package provided by CSIRO Division of Wildlife and Ecology. In these analyses, the data matrix showing presence or absence of each animal species at each site was first converted to a symmetric matrix of biotic similarity between pairs of sites using the Bray-Curtis similarity index. The similarity matrix was agglomeratively clustered using ranked data and group-averaging, as suggested by Clarke (1993), and presented using MDS as the best graphical depiction in two dimensions of the biotic similarities between sites. The usefulness of this two dimensional display of relationships between sites is indicated by the stress statistic, which is <0.1 if the depiction of relationships is good, and >0.2 if the depiction is poor (Clarke, 1993).

Preliminary analyses indicated that regional trends could not be deciphered using individual site data because the biota at each site was primarily influenced by local environmental conditions. Consequently, adjacent sites encompassing a range of habitats were amalgamated by dividing the Tasmanian coast into 17 zones on subjective grounds, with each zone chosen so as to be bounded by prominent geographical features and to include approximately 50 km of coastline (Fig. 1). Data from all surveyed sites within each zone were then amalgamated, and the presence or absence of species within each zone noted. The presence/absence data matrix (columns zones, rows species) for reef biota, beach-washed shells and soft-sediment fishes were then analysed separately using MDS to display the biotic relationships between zones, and to identify which zones grouped together.

Relationships between zones were partly affected by the sampling effort within each zone and total number of species observed, so patterns were further clarified by assuming the presence of species in a zone if that species occurred in other zones both to the north and the south (and in other zones to the east and west along the northern Tasmanian coastline).

GIS analysis of reef data

Information on the presence and abundance of species at the 151 marine reef sites investigated was loaded onto the Tasmanian Parks and Wildlife Service GENASYS Geographic Information System (GIS). Plots were produced showing the locations around Tasmania that each species had been observed during reef censuses. The distribution of each species was then mapped by filling in gaps between sites at which species have been recorded. Examples of the output produced by this process are displayed in Appendix 2. A total of 21 fish, 4 invertebrate and 10 plant species were sighted at only a single locality or at widely separated localities, so were excluded from analyses because of uncertainty about their distribution patterns, leaving 78 fish, 40 invertebrate and 77 plant species in analyses (Table 1).

The distribution maps were then overlayed, and a species richness map produced that sums the number of species spanning each 1 km sector of the coastline. Gap analysis was used to produce a similar map after species found during surveys to occur within existing marine reserves had been removed from the data matrix. This map indicated sections of the Tasmanian coastline with the highest number of species not accommodated within existing reserves (i.e. the regions most in need of protection in order to maximise biodiversity within the reserve system).

Data on the distribution of reef plants and animals were also analysed using the ordination procedure Detrended Correspondence Analysis (DECORANA; Hill *et al.*, 1980) to examine the composition of assemblages within 1 km sectors. The DECORANA program identified the degree of biotic similarity between different sections of the coast. These were plotted using GIS onto a map of Tasmania, with the biotic relationships along the coast indicated by colour coding so that apparent differences in colour reflect differences among assemblages (Peters, 1990).

Finally, the interpolated reef data were analysed using an edge detection method known as Ecotone Analysis (Peters, 1990) that measures gradients in species composition along the coastal buffer. In this analysis, an index of biotic overlap was calculated between overlapping 10 km x 10 km neighbourhoods, centred 5 km apart along the length of the coast. Sectors with rapid biotic change are identified by this procedure and indicate boundaries between bioregions.

Table 1. Species used in analyses involving GIS.

Fishes	Echinoderms	Plants
Acanthaluteres spilomelanurus	*Astrostole scabra*	*Abjohnia laetevirens*
Aetapcus maculatus	*Austrofromia polypora*	*Acrocarpia paniculata*
Apogon conspersus	*Centrostephanus rodgersii*	*Ballia callitricha*
Aracana aurita	*Comanthus tasmaniae*	*Ballia scoparia*
Atypichthys strigatus	*Comanthus trichoptera*	*Callophyllis lambertii*
Bovichthys variegatus	*Coscinasterias calamaria*	*Callophyllis rangiferinus*
Caesioperca lepidoptera	*Echinaster arcystatus*	*Carpoglossum confluens*
Caesioperca rasor	*Goniocidaris tubaria*	*Carpomitra costata*
Cephaloscyllium laticeps	*Heliocidaris erythrogramma*	*Caulerpa annulata*
Cheilodactylus nigripes	*Holopneustes inflatus*	*Caulerpa brownii*
Cheilodactylus spectabilis	*Holopneustes porosissimus*	*Caulerpa cactoides*
Chromis hypsilepis	*Nectria macrobranchia*	*Caulerpa flexilis*
Conger verreauxi	*Nectria ocellata*	*Caulerpa flexilis var. muelleri*
Dactylophora nigricans	*Nepanthia troughtoni*	*Caulerpa geminata*
Dactylosargus arctidens	*Patiriella brevispina*	*Caulerpa longifolia*
Dinolestes lewini	*Patiriella calcar*	*Caulerpa obscura*
Diodon nichthemerus	*Patiriella regularis*	*Caulerpa scalpelliformis*
Dotalabrus aurantiacus	*Pentagonaster duebeni*	*Caulerpa simplisciuscula*
Ellerkeldia maccullochi	*Petricia vernicina*	*Caulerpa trifaria*
Enoplosus armatus	*Plectaster decanus*	*Caulerpa vesiculifera*
Eubalichthys gunnii	*Stichopus mollis*	*Caulocustis uvifera*
Forsterygion varium	*Tosia australis*	*Caulocystis cephalornithos*
Genypterus tigerinus	*Tosia magnifica*	*Codium australicum*
Girella elevata	*Uniophora granifera*	*Codium dimorphum*
Girella tricuspidata		*Codium pomoides*
Gnathanacanthus goetzii	**Molluscs**	*Cystophora monilifera*
Haletta semifasciata	*Argobuccinium vexillum*	*Cystophora moniliformis*
Heteroclinus forsteri	*Cabestana spengleri*	*Cystophora platylobium*
Heteroclinus johnstoni	*Charonia rubicunda*	*Cystophora polycistidea*
Heterodontus portusjacksoni	*Haliotis laevigatus*	*Cystophora retorta*
Hippocampus abdominalis	*Haliotis ruber*	*Cystophora retroflexa*
Hypoplectrodes nigrorubrum	*Haliotis scalaris*	*Cystophora subfarcinata*
Kyphosus sydneyanus	*Penion mandarinus*	*Cystophora xiphocarpa*
Latridopsis forsteri	*Pleuroploca australasia*	*Delisea pulchra*
Latris lineata	*Ranella australasia*	*Desmarestia ligulata*
Latropiscis purpurissatus	*Sepia apama*	*Dictymenia harveyana*
Lotella rhacinus	*Thais orbita*	*Dictyopteris muelleri*
Melambaphes zebra	*Turbo undulatus*	*Dictyosphaeria sericea*
Mendosoma allporti		*Durvillaea potatorum*
Meuschenia australis		*Ecklonia radiata*
Meuschenia flavolineata		*Euptilota articulata*

Table 1 (cont.). Species used in analyses involving GIS.

Fishes	**Crustaceans**	**Plants**
Meuschenia freycineti	*Jasus edwardsii*	*Hemineura frondosa*
Meuschenia hippocrepis	*Nectocarcinus tuberculatus*	*Hypnea episcopalis*
Meuschenia venusta	*Plagusia chabrus*	*Jeannerettia lobata*
Neoodax balteatus	*Trizopagurus strigimanus*	*Kallymenia cribrosa*
Neosebastes scorpaenoides		*Lenormandia marginata*
Norfolkia striaticeps		*Lenormandia muelleri*
Notalabrus fucicola		*Lessonia corrugata*
Notalabrus tetricus		*Macrocystis angustifolia*
Odax acroptilus		*Macrocystis pyrifera*
Odax cyanomelas		*Melanthalia obtusata*
Omegophora armillata		*Perithalia cordata*
Ophthalmolepis lineolatus		*Phacellocarpus labillardieri*
Parablennius tasmanianus		*Phyllospora comosa*
Parascyllium variolatum		*Plocamium angustum*
Paratrachichthys trailli		*Plocamium cartilagineum*
Parika scaber		*Plocamium dilatatum*
Parma microlepis		*Plocamium leptophyllum*
Parma victoriae		*Plocamium mertensii*
Pempheris multiradiatus		*Plocamium potagiatum*
Penicipelta vittiger		*Plocamium preissianum*
Pentaceropsis recurvirostris		*Ptilonia australicum*
Phyllopteryx taeniolatus		*Sargassum decipiens*
Pictilabrus laticlavius		*Sargassum fallax*
Pseudolabrus psittaculus		*Sargassum heteromorphum*
Pseudophycis bachus		*Sargassum sonderi*
Scorpaena ergastulorum		*Sargassum varians*
Scorpis aequipinnis		*Sargassum verruculosum*
Scorpis lineolatus		*Sargassum vestitum*
Seriolella brama		*Scaberia agardhii*
Siphonognathus attenuatus		*Seirococcus axillaris*
Siphonognathus beddomei		*Sonderopelta coriacea*
Sphyraena novaehollandiae		*Thamnoclonium dichotomum*
Thamnaconus degeni		*Undaria pinatifida*
Trachinops caudimaculatus		*Xiphophora chondrophylla*
Trachurus declivis		*Xiphophora gladiata*
Upeneichthys vlaminghii		*Zonaria turneriana*
Urolophus cruciatus		

RESULTS

Sea Surface Temperatures

Mean February and July surface water temperatures between 1989 and 1992 are shown in Figs 2a and 2b. Oceanic temperatures in February were substantially warmer in the northeastern Bass Strait region, particularly around the Kent and Furneaux Groups, than elsewhere around Tasmania, with a cold water intrusion reaching the southern coast and southeastern Bruny Island. The northern Tasmanian coastline was slightly (≈1°C) warmer than the eastern and western coastlines, and localised heating occurred adjacent to the coast in shallow sheltered habitats. This latter effect is particularly noticeable because temperature measurements were recorded in the late afternoon.

During July, warm water intrusions occurred offshore along the northeastern and northwestern coastlines. The northeastern intrusion, the East Australian Current, followed the Continental Shelf Break and did not closely approach the coast. However, the northwestern intrusion, the poorly known tail of the winter-flowing Leeuwin Current (Godfrey and Ridgeway, 1985), extended close inshore at King Island and may have also impinged on the northern section of the western Tasmanian coast. Sea surface temperatures in July varied little throughout inshore Tasmanian waters from the south coast to the Furneaux Group, except for localised cooling in the large sheltered embayments, particularly Great Oyster Bay, Storm Bay and D'Entrecasteaux Channel on the east coast.

Multidimensional scaling of biotic data

The reef data set was initially analysed by MDS, with output displayed in Fig. 3 as the best spatial representation in two dimensions of the biotic relationships between all 5 m deep reef sites. The stress statistic associated with this plot is 0.31, indicating a very poor two dimensional display of biotic relationships. Sites form a cloud of points in this analysis, with no strong separation into groups, indicating that sites were located along clines in primary environmental conditions without major disjunctions.

The primary influence on biota at individual sites appears to be wave exposure (or a correlate thereof). Sheltered sites, as indicated by the presence of the calm water algal species *Cystophora retroflexa* (Edgar, 1984b), are congregated at the right-hand side of Fig. 3, while maximally exposed sites, as indicated by the presence of the wave-exposed alga *Durvillaea potatorum*, are clustered at the left of the figure. Water temperature was less strongly correlated with the biota, although a clear separation is apparent in Fig. 4 between reef assemblages found around the northeastern Bass Strait islands (Hogan, Curtis and the Kent Group) and assemblages found along the south coast.

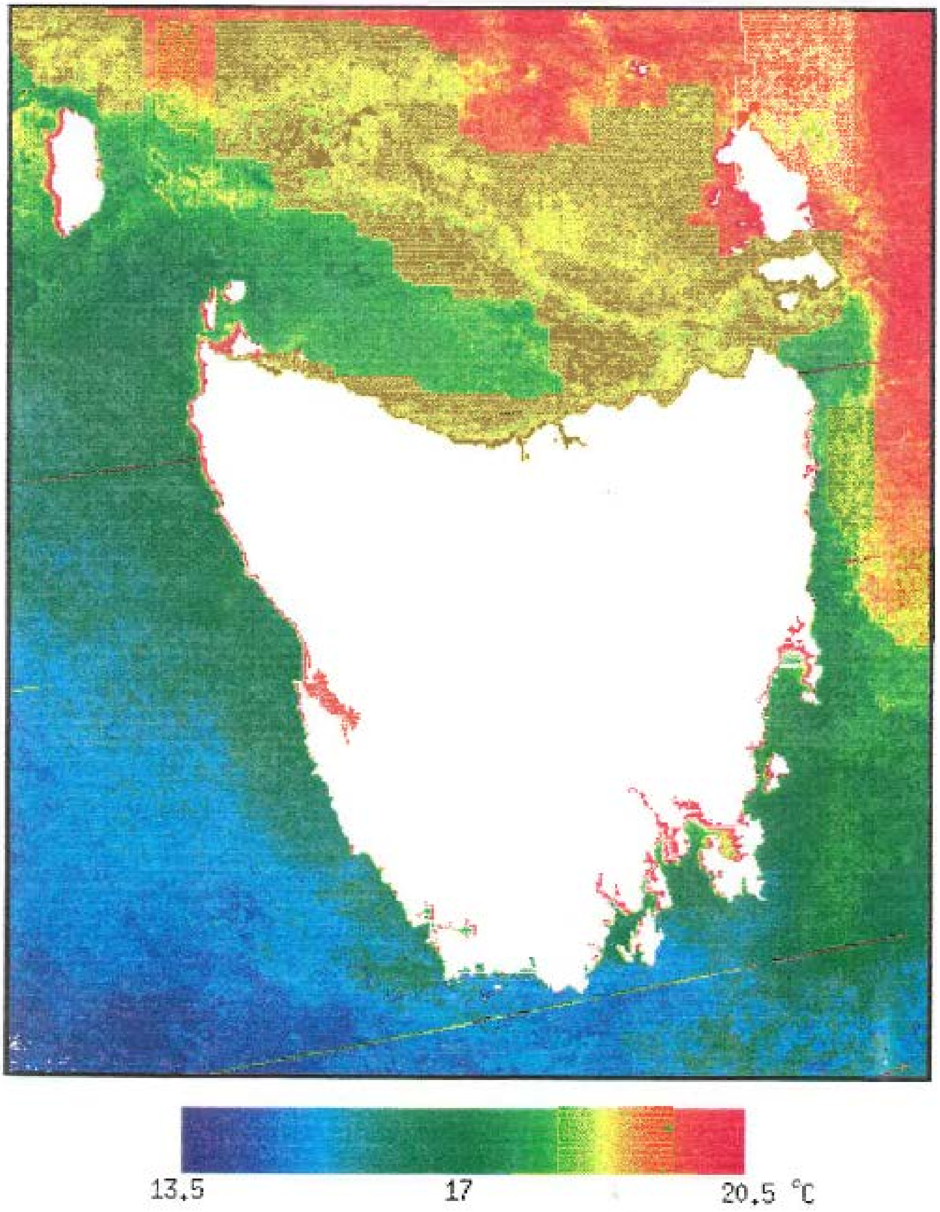

Fig. 2a. Mean February sea surface temperatures recorded in the Tasmanian region between 1989 and 1992.

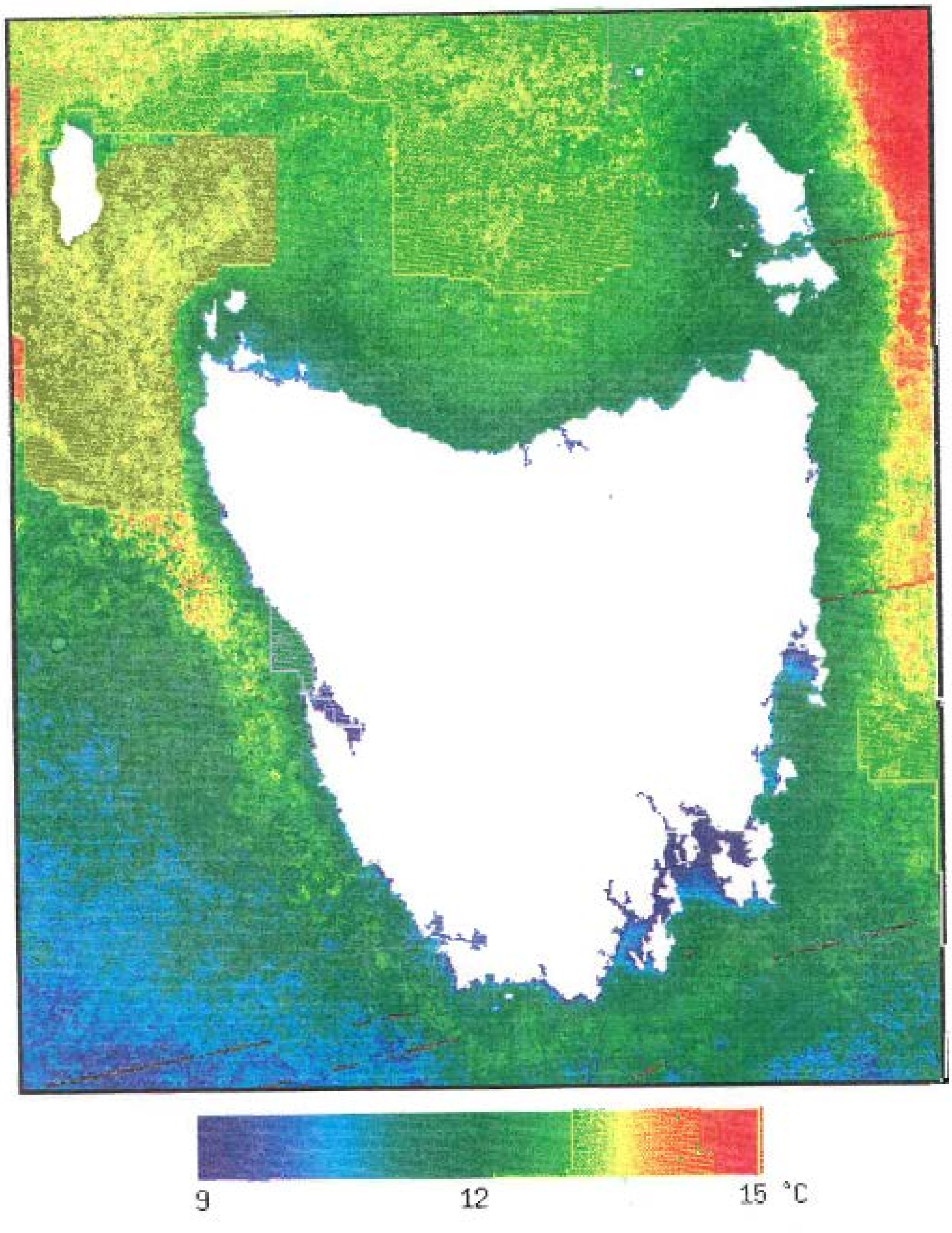

Fig. 2b. Mean July sea surface temperatures recorded in the Tasmanian region between 1989 and 1992.

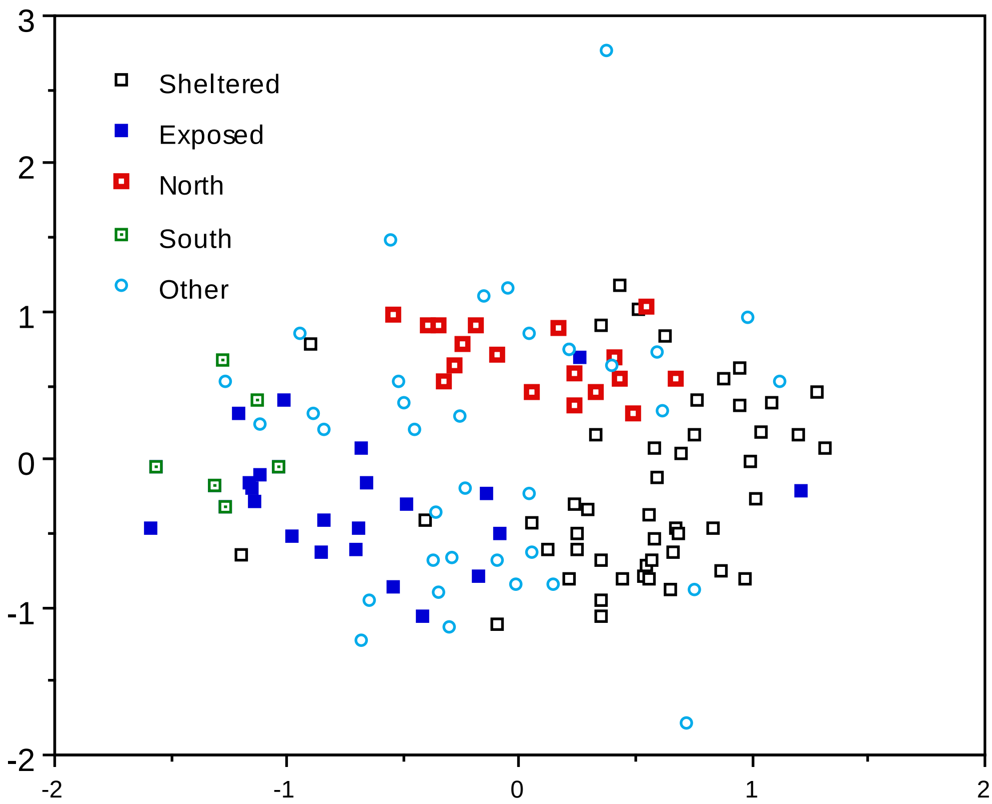

Fig. 3. Results of MDS using presence/absence data for plants, invertebrates and fishes recorded at 5 m depth reef sites. Sites in the northernmost (Curtis Island, Hogan Island and Kent Group) and southernmost (southern and southwestern Tasmanian) regions are distinguished, as are the most sheltered and exposed sites. Sheltered sites were identified by the presence the alga *Cystophora retroflexa*, a species that occurs abundantly only in calm-water habitats (Edgar, 1983), and exposed sites by the presence of the bull “kelp” *Durvillaea potatorum*, a plant that dominates sites with high levels of wave exposure (Edgar, 1984b).

When presence/absence data from all reef sites within each of the 17 zones shown in Fig. 1 were amalgamated before analysis by MDS, the Bass Strait zones formed a distinct biotic grouping, as did zones along the eastern, southern and western coasts of Tasmania (Fig. 4). No smaller subgroupings were apparent. A stress statistic of 0.12 was associated with this plot.

A clearer picture emerged when interpolated records were included in addition to the direct records in the MDS analysis (i.e., species were assumed to occur within a zone when recorded north and south of that zone; Fig. 5). In this analysis, the three zones present along the northern Tasmanian coast grouped closely together, as did the three northern east coast zones and the three southern east coast zones, and a diffuse association between the four southern and western coastal zones was also evident. The stress statistic associated with this MDS plot (=0.06) was lower than for the previous analysis (0.12), indicating a much better two-dimensional depiction of results.

Multidimensional scaling of the beach-washed shell data using the same interpolation technique produced a different pattern (Fig. 6). The mollusc faunas at King Island, the Furneaux Group and the south coast formed outlying groups, with no clear dichotomy separating the Bass Strait fauna from that found in more southern zones. A similar analysis using seine-collected fishes also indicated that the faunas at King Island and the Furneaux Group were quite different to those recorded elsewhere (Fig. 7). The three northern coastal zones grouped closely together, as did the east coast zones from Maria Island northwards, and the two southeasternmost zones. The stress statistics associated with the MDS analyses were extremely low for both shell (=0.04) and fish (=0.06) data, indicating good two-dimensional depictions of relationships.

GIS analysis of reef data

The highest-resolution regional analysis of reef data is shown in Fig. 8, where MDS was used to depict the biotic relationships between all reef sites examined. In this analysis, which is otherwise identical to the analysis used to derive Fig. 3, interpolated data indicating the presence of species at a site has been added from the GIS to the data matrix when the distribution of a species overlaps that site. Most of the points shown in Fig. 8 represent more than one site with identical species compositions, hence the apparent lower number of data points plotted compared with Fig. 3. The stress statistic associated with the plot is 0.07.

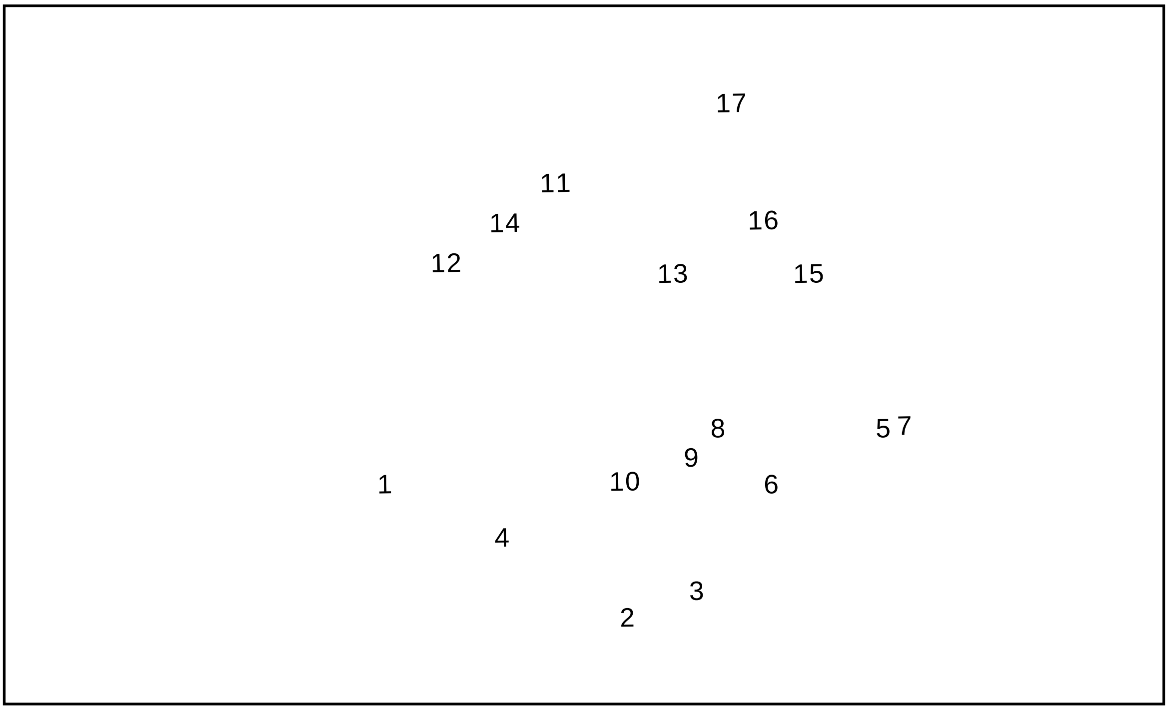

Fig. 4. Results of MDS using presence/absence data for plants, invertebrates and fishes recorded within the 17 zones shown in Fig. 1.

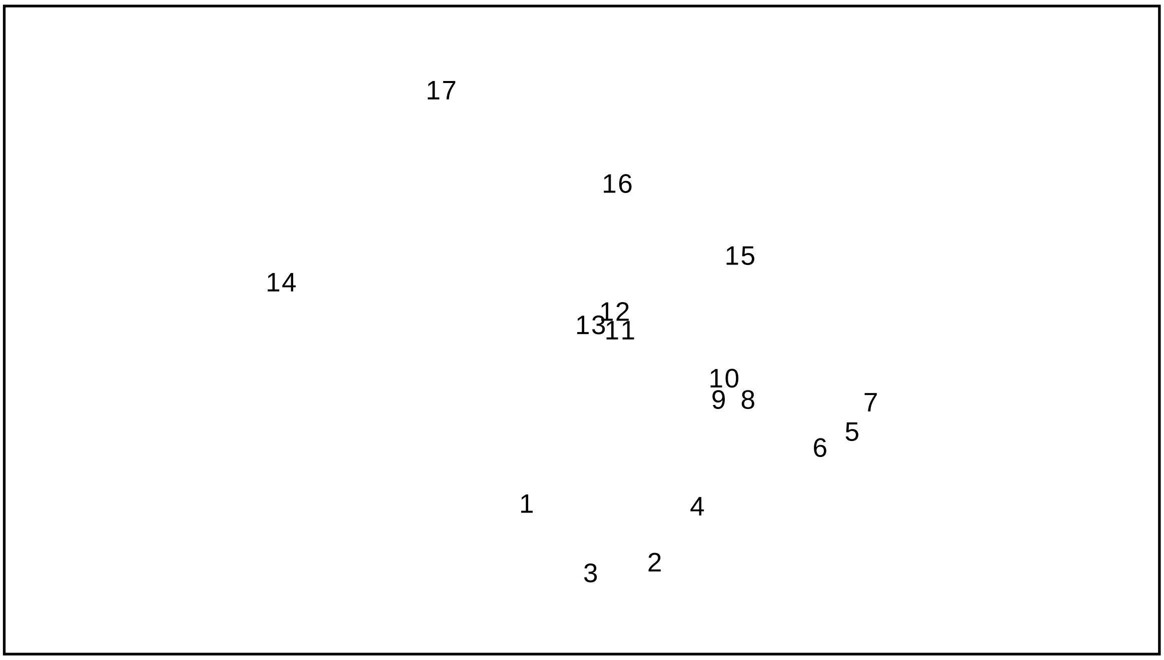

Fig. 5. Results of MDS using recorded and interpolated data on the distribution of plants, invertebrates and fishes within the 17 zones shown in Fig. 1.

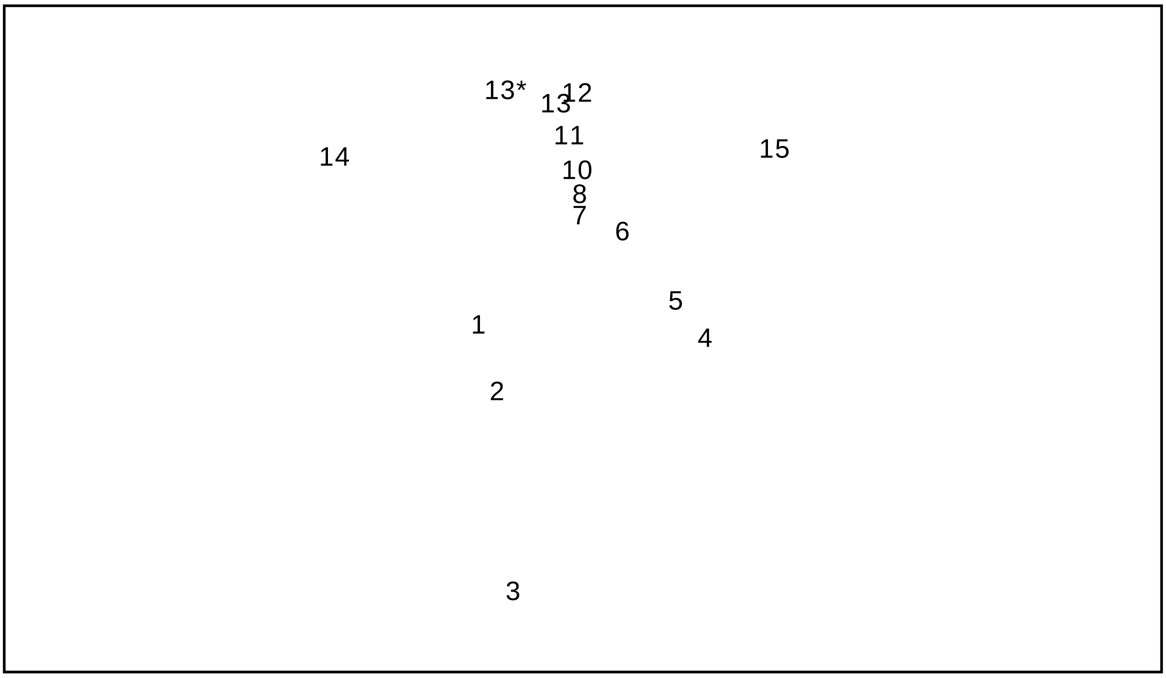

Fig. 6. Results of MDS using recorded and interpolated data on the distribution of beach-washed shells within 14 zones (shown in Fig. 1). Zone 13 (western north coast) has been divided into two, with the area denoted by 13* extending west of Port Latta. No data were collected from zones 9, 16 and 17.

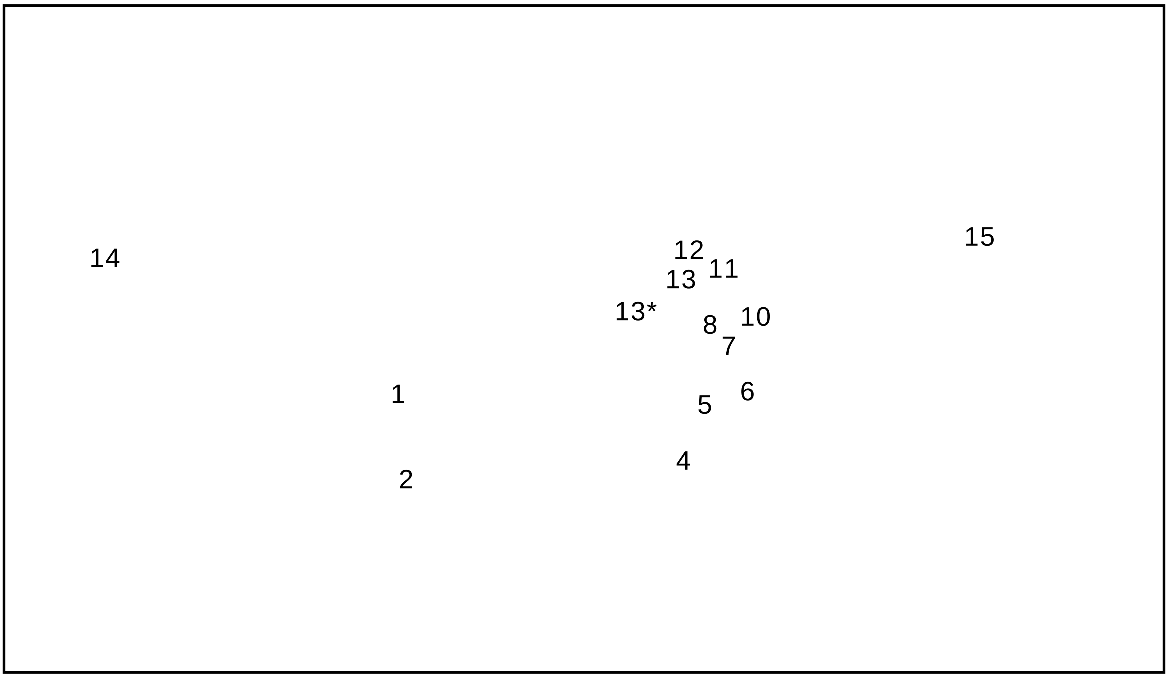

Fig. 7. Results of MDS using recorded and interpolated data on the distribution of soft-sediment fishes within 13 zones (shown in Fig. 1). Zone 13 (western north coast)

has been divided into two, with the area denoted by 13* extending west of Port Latta. No data were collected from zones 3, 9, 16 and 17.

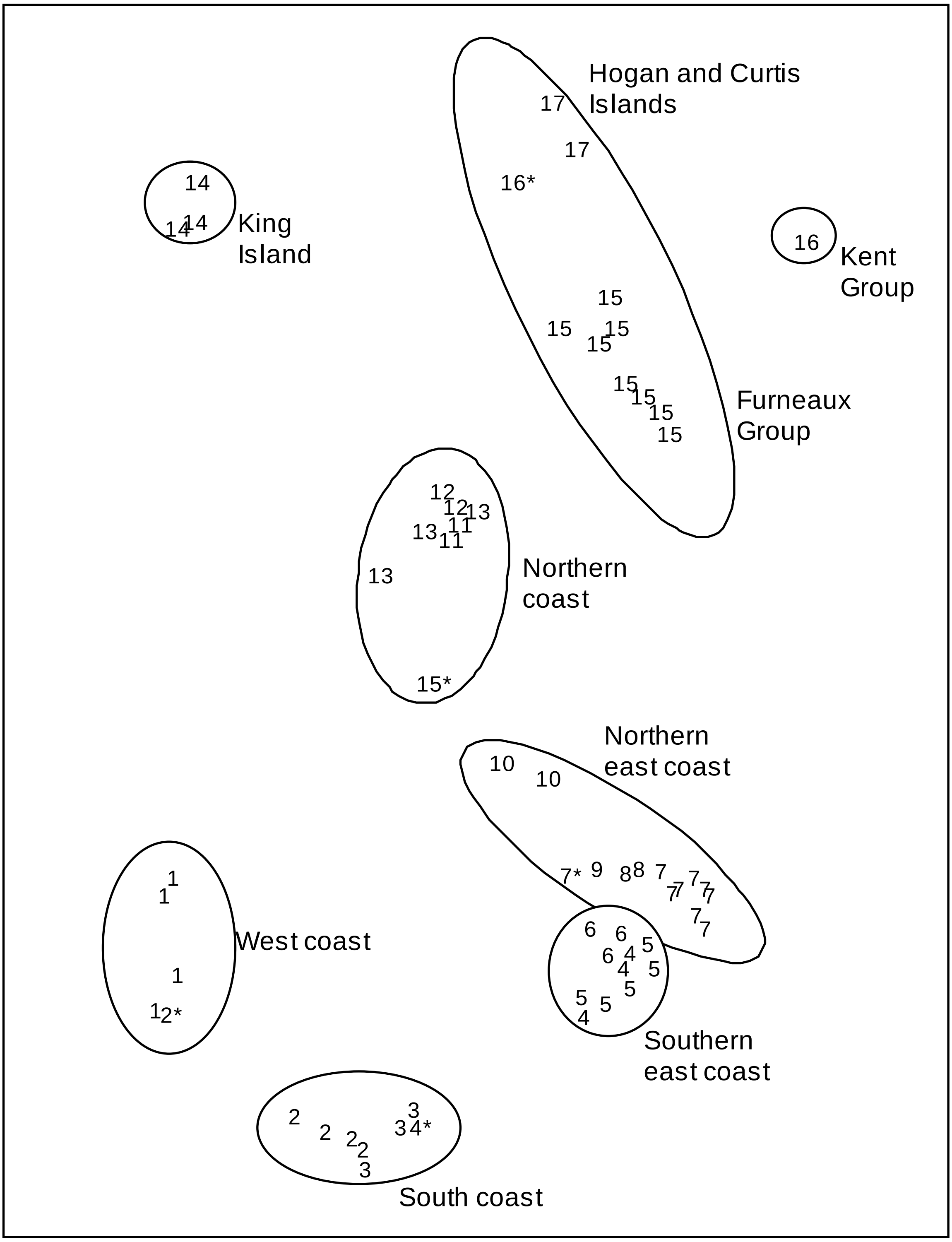

Fig. 8. Results of MDS using recorded and interpolated data on the distribution of reef biota at investigated sites. Sites often overlap, in which case only one data point is shown. Individual sites are indicated by zone codes (see Fig. 1), and are placed into bioregional groupings. Outlying sites are as follows: 2*, Brier Holme Bay and Low Rocky Point (overlapping sites); 4*, Actaeon Island; 7*, Ile des Phoques; 15*, Swan

Island; 16*, Judgement Rocks and South West Island (overlapping sites).

Several regional groupings can be identified amongst reef sites shown in Fig. 8: (i) King Island sites (zone 14), (ii) northern Tasmanian coastal sites (zones 11,12,13), (iii) Furneaux Group sites (zone 15), (iv) Kent Group sites (zone 16), (v) the northeasternmost Bass Strait Island sites (zone 17), (vi) western Tasmanian sites (zone 1), (vii) southern Tasmanian sites (zones 2,3), and (viii) eastern Tasmanian sites (zones 4,5,6,7,8,9,10). The latter grouping is the most heterogeneous and could perhaps be further subdivided. In several cases, the zone boundaries chosen on subjective grounds (see Fig. 1) did not correspond with bioregional boundaries. Zone 1 should be extended south to encompass Low Rocky Point and Brier Holme Bay (2*), zone 3 should be extended northwards to include Actaeon Islands (4*), and zone 17 should be extended southwards to include two outlying islands (Judgement Rocks and South West Island) associated with the Kent Group (16*). Swan Island (15*) possesses a reef biota intermediate between that found along the northern and eastern Tasmanian coastlines, and is not closely related to the Furneaux Group in which it was initially placed (zone 15).

The regional patterns identified for the total reef fauna remained relatively consistent when fish, invertebrate and plant data sets were analysed independently (Figs 9, 10 and 11). The major differences using fish data (Fig. 9) when compared to total reef data (Fig. 8) were that the Furneaux Group (zone 15) did not separate from the northeasternmost Bass Strait islands (zone 17), and that the eastern Tasmanian coast could be divided into three subgroupings: northern east (zone 10), central east (zones 7, 8 and 9), and southern east (zones 4, 5 and 6). No major differences were found in groups derived using invertebrate (fig. 10) compared with total reef data. The only major difference using algal data (fig. 11) was that the Kent Group did not separate as a biotic grouping from other northeastern Bass Strait islands. The stress statistic was low for all these analyses (0.08, 0.08 and 0.10 for fishes, invertebrates and plants, respectively) indicating good two-dimensional depictions of relationships.

Analysis of GIS distribution data indicated that species richness of reef plants and animals around the Tasmanian coastline was highest in the vicinity of Maria Island (central eastern coast) followed by southeastern Tasmania in the vicinity of Bruny Island (Fig. 12). These patterns reflected peaks in species richness for both fishes (Fig. 13) and plants (Fig. 15), while the species richness of invertebrates (Fig. 14) was consistently high around both the eastern and northern Tasmanian coasts. An anomalously high number of fish species occurred at the Kent Group in northeastern Bass Strait.

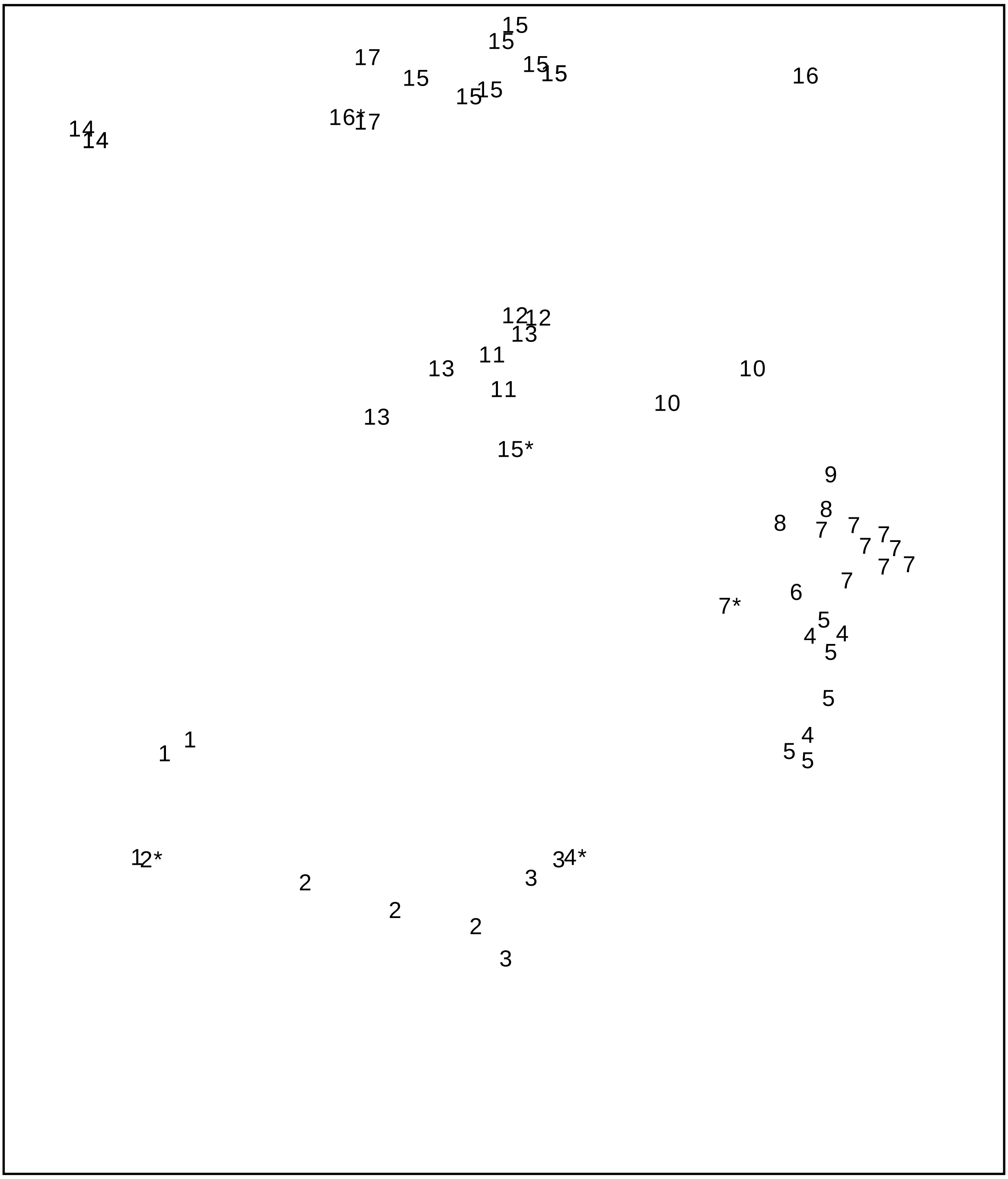

Fig. 9. Results of MDS using recorded and interpolated data on the distribution of reef fishes at the investigated sites. Individual sites are indicated by zone codes (see Fig. 1), with anomalous sites coded using asterisks as in Fig. 8.

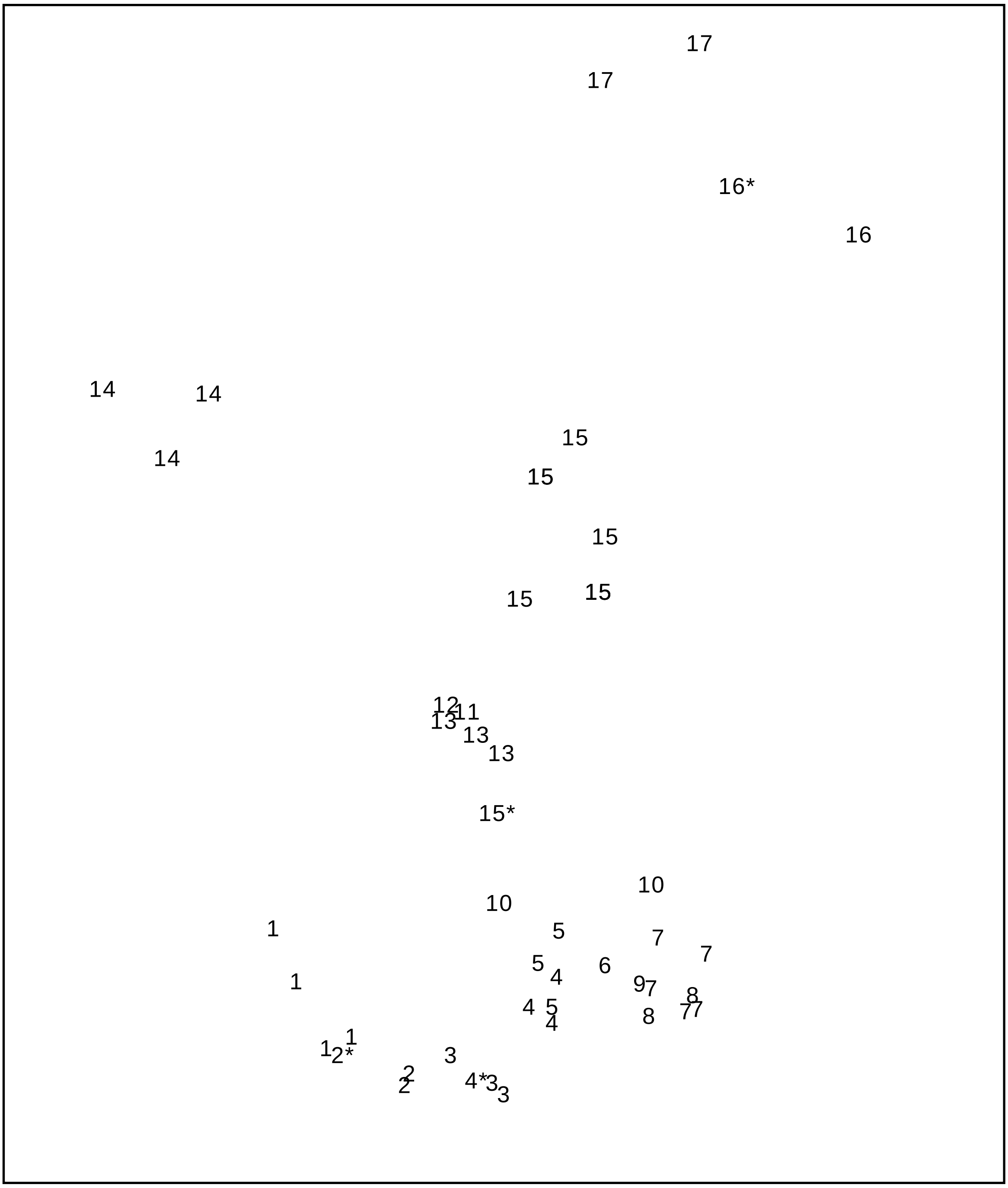

Fig. 10. Results of MDS using recorded and interpolated data on the distribution of reef invertebrates at the investigated sites. Individual sites are indicated by zone codes (see Fig. 1), with anomalous sites coded using asterisks as in Fig. 8.

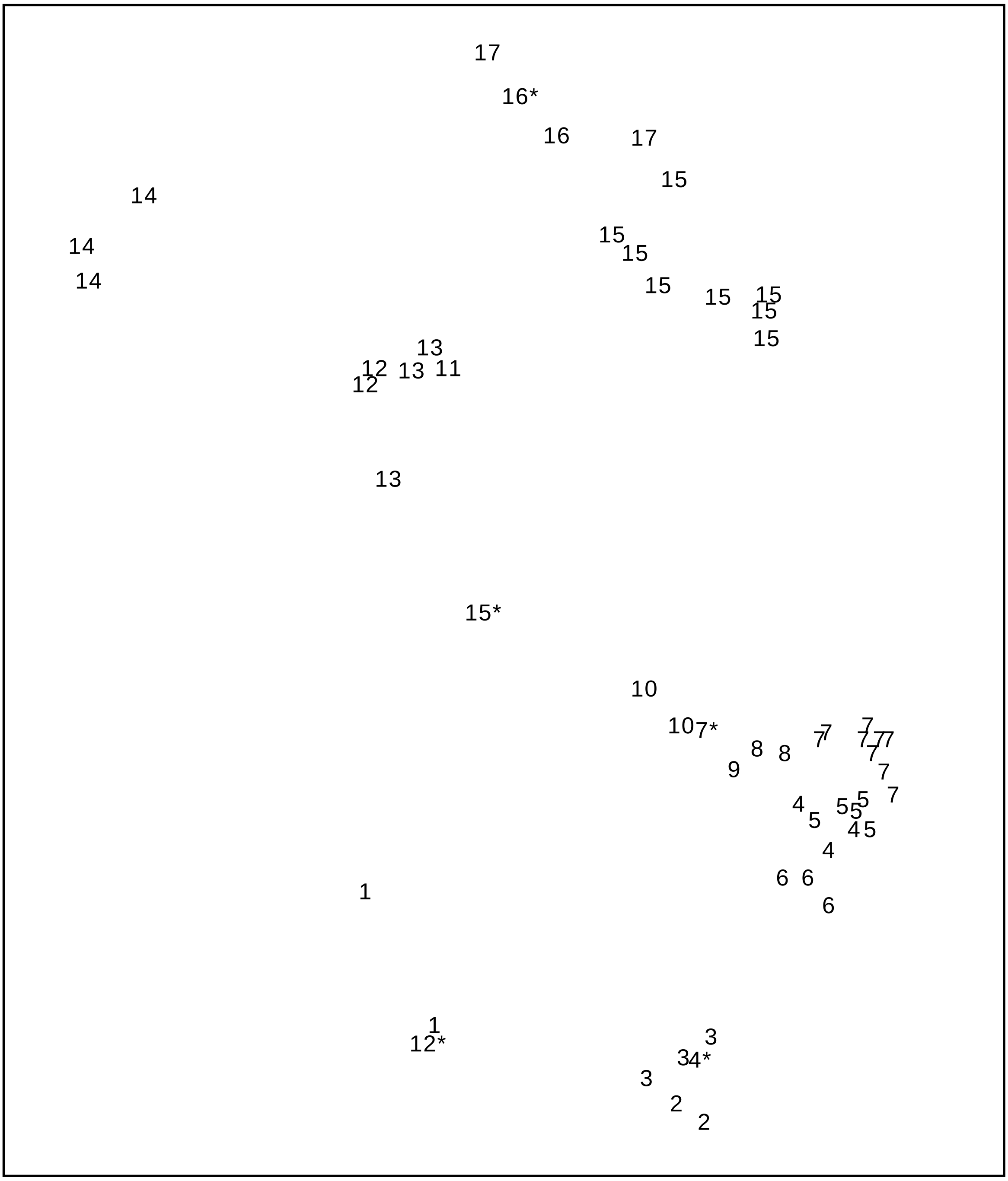

Fig. 11. Results of MDS using recorded and interpolated data on the distribution of reef plants at the investigated sites. Individual sites are indicated by zone codes (see Fig. 1), with anomalous sites coded using asterisks as in Fig. 8.

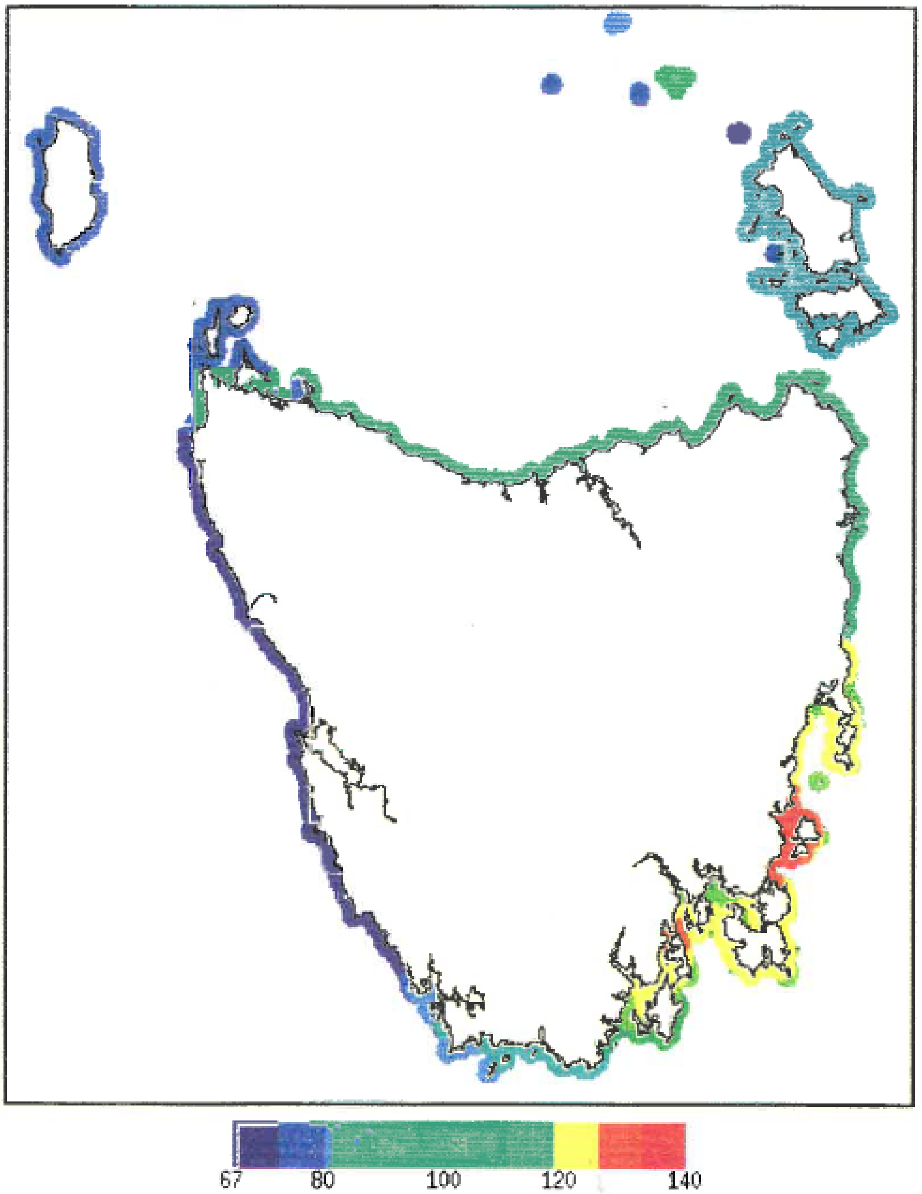

Fig. 12. Number of recorded and interpolated species (fishes, invertebrates and plants) found on reefs in different areas of the coast out of a total of 195 species on GIS data base.

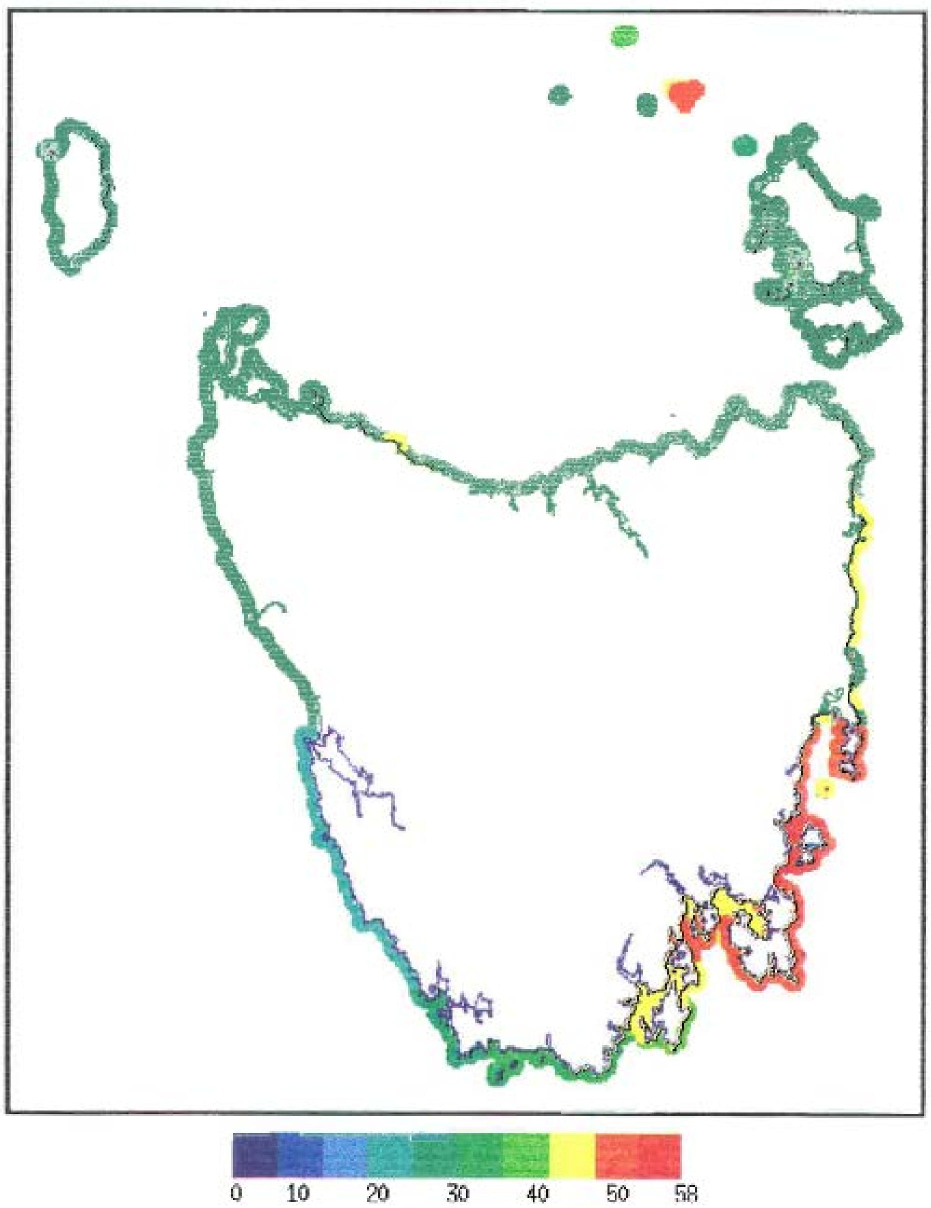

Fig. 13. Number of recorded and interpolated fish species found on reefs in different areas of the coast out of a total of 78 species on GIS data base.

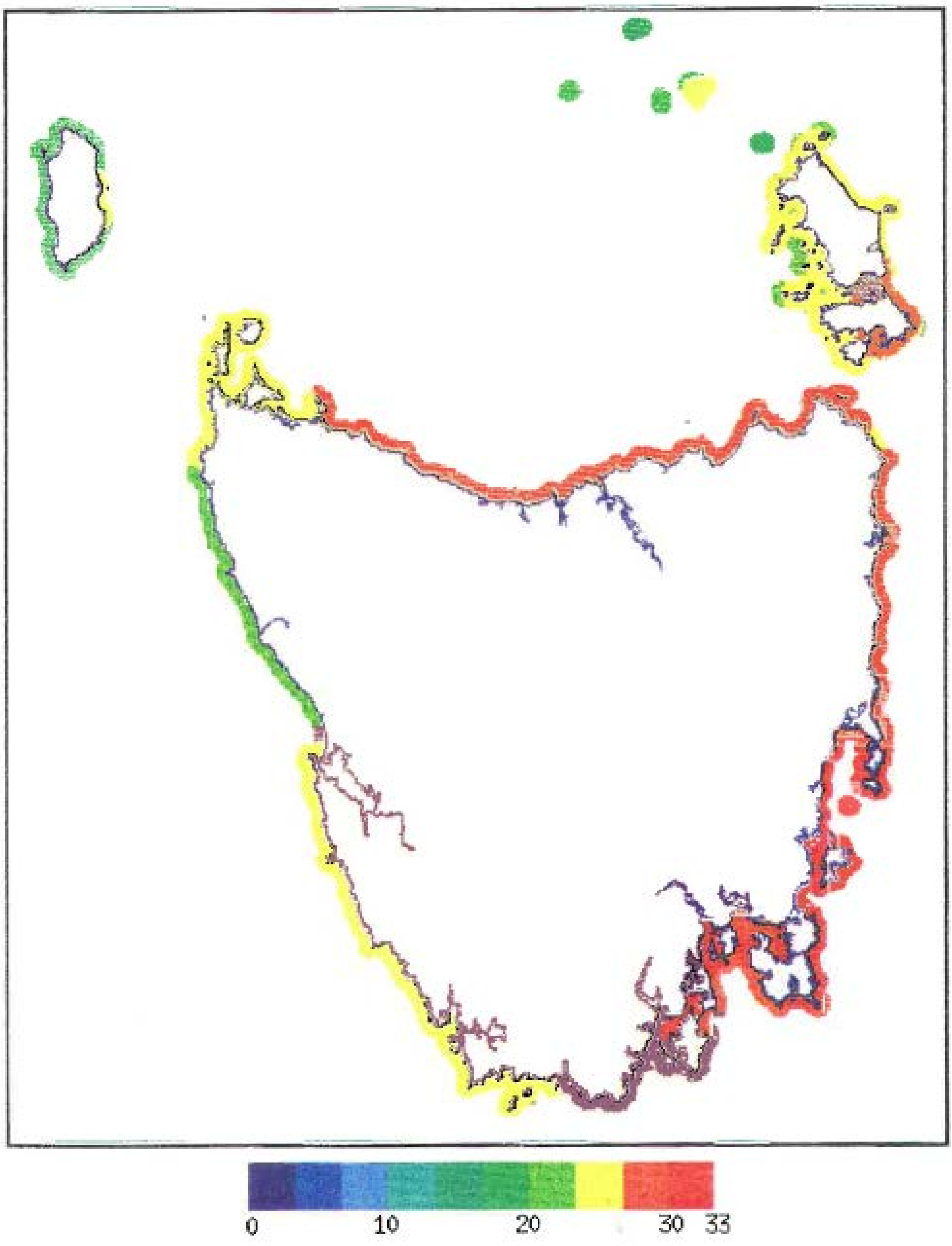

Fig. 14. Number of recorded and interpolated invertebrate species found on reefs in different areas of the coast out of a total of 40 species on GIS data base.

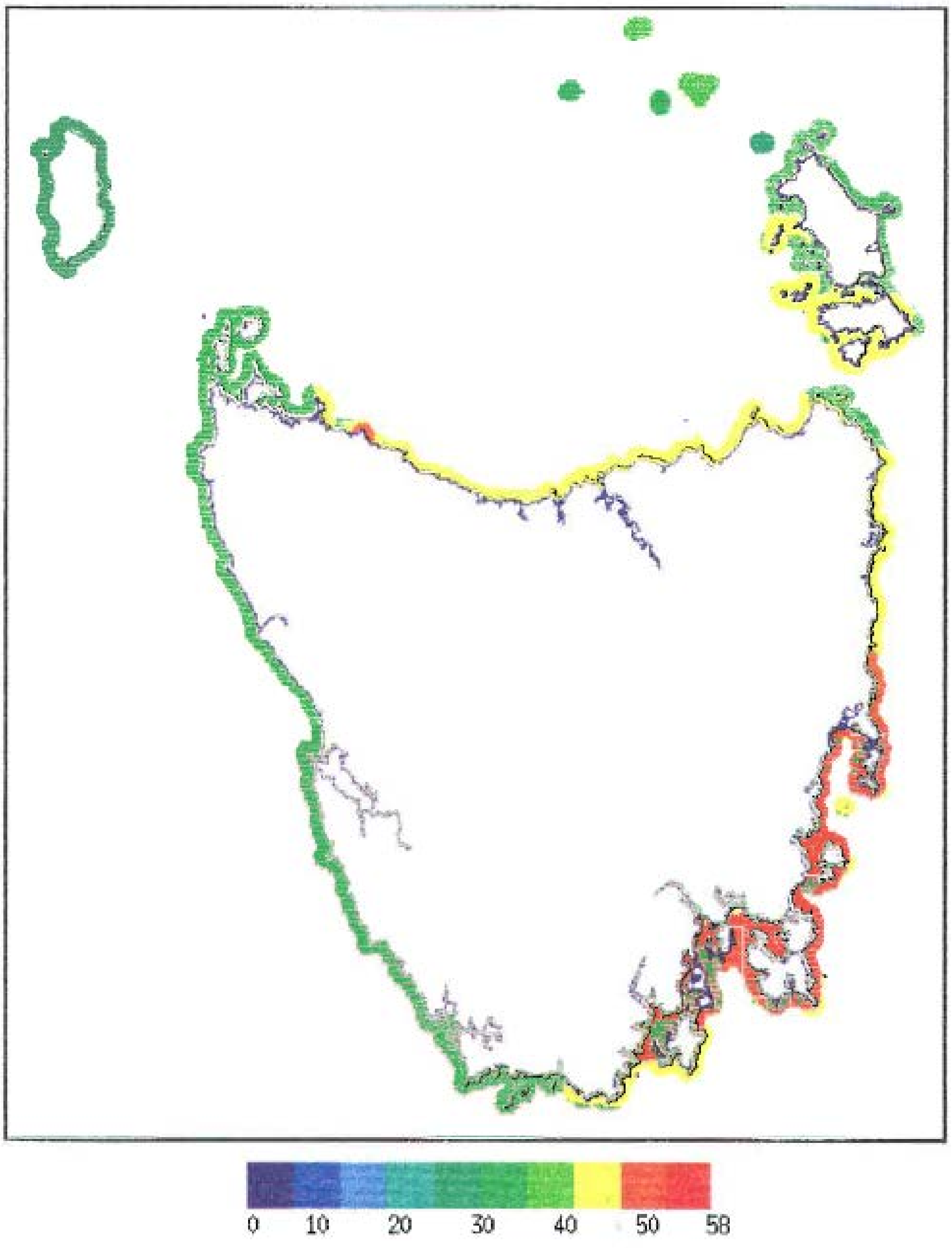

Fig. 15. Number of recorded and interpolated plant species found on reefs in different areas of the coast out of a total of 77 species on GIS data base.

The high species richness of reef plants and animals in southeastern Tasmania is partially explained by high numbers of species at individual sites; however, the number of species observed on individual transects was similar along the northern Tasmanian coastline to that found in transects along the eastern coast (Table 2; Appendix 1). The absence of maximally exposed habitats on the north coast, and therefore reduced variety of habitats compared with eastern Tasmania, contributed to the lower overall numbers in the north, although the patterns shown in Fig. 12 are probably alse affected by the greater number of sites sampled in the east. The low marine species richness at King Island is certainly an artefact caused by only six sites having been censused in that area. Species were not classed as occurring at King Island (and the northeastern Bass Strait islands) unless directly recorded, whereas species found in northern and eastern Tasmania were often inferred to occur because of records to the north and south. Similarly, species were not added to south coast sites unless recorded at that site or nearby. For this region the number of fish and invertebrate species is nevertheless extremely low (Table 2).

Table 2. Summary statistics showing mean (x), minimum (min) and maximum (max) number of taxa recorded during censuses at sites in the different Tasmanian bioregions. Sites within estuarine Bathurst Channel are not included. Values for all sites examined are shown in Appendix 1.

	Fishes			Invertebrates			Plants			All taxa		
	x	min	max	x	min	max	x	min	max	x	min	max
West coast (Franklin)	5.4	1	11	7.5	5	11	14.2	7	23	27.1	16	41
South coast (Davey)	7.9	1	16	6.8	4	16	20.6	7	35	34.0	10	46
Southeast coast (Bruny)	14.3	5	21	12.3	4	19	21.9	9	33	48.4	33	63
Northeast coast (Freycinet)	15.4	6	26	12.2	4	20	16.2	3	31	43.8	20	66
North coast (Boags)	16.6	7	29	12.3	7	17	19.9	13	28	48.6	31	62
Furneaux, Hogan and Curtis Groups (Flinders)	13	4	22	10.5	6	17	19.3	3	29	42.9	17	57
Kent Group (Gippsland)	23.4	16	34	11.0	8	14	17.0	7	28	51.4	33	59
King Island (Otway)	10.3	4	18	11.0	5	17	22.2	18	28	44.8	33	57

If species recorded within existing marine reserves were excluded from the analysis of reef species richness, the highest number of species was found to occur along the northern Tasmanian coastline and the Bass Strait islands, particularly the Kent Group (Fig. 16). This result accords with the result of the DECORANA analysis (Fig. 17), which shows that the ecosystem in Bass Strait, including that along the northern Tasmanian coastline from Stanley to Cape Portland, is substantially different from that found along the eastern, southern and western Tasmanian coasts. The principal eigenvector scores produced by

DECORANA analysis were positively associated with the Bass Strait region and negatively associated with the southern Tasmanian region. Species with high and low principal eigenvector scores, which are therefore characteristic of one or the other of these two areas, are listed in Tables 3 and 4.

Nearly all of the species listed in Table 3 have not been recorded south of Bass Strait, and the few that do occur along the east coast (viz. *Girella elevata, Enoplosus armatus, Cystophora monilifera, Caulerpa cactoides*) are rare. By contrast, a number of species listed in Table 4 (e.g. *Hippocampus abdominalis, Phyllopteryx taeniolatus, Caesioperca lepidoptera, Hypnea ramentacea* and *Lenormandia marginata*) are widespread on the Australian mainland, so cannot be considered truly representative of southern Tasmanian waters.

The Ecotone Analysis supported the DECORANA analysis by also showing major biotic disjunctions in the vicinity of Stanley and Cape Portland (Fig. 18). The next most important disjunctions were located just north of Port Davey (southwestern Tasmania), near Southport (southeastern Tasmania), near southern Maria Island (eastern Tasmania), and near Eddystone Point (northeastern Tasmania).

Table 3. Species with highest principal eigenvector scores in DECORANA analysis. The principal eigenvector scores produced by DECORANA analysis were positively associated with the Bass Strait region, hence these species are characteristic of the Bassian bioprovince in Tasmania.

Fishes	**Invertebrates**	**Algae**
Latropiscis purpurissatus	*Nepanthia troughtoni*	*Caulerpa vesiculifera*
Ellerkeldia maccullochi	*Echinaster arcystatus*	*Cystophora monilifera*
Girella elevata	*Nectria macrobrachia*	*Cystophora polycistidea*
Kyphosus sydneyanus	*Holopneustes porosissimus*	*Scaberia agardhii*
Enoplosus armatus	*Haliotis laevigatus*	*Xiphophora chondrophylla*
Parma victoriae	*Haliotis scalaris*	*Sargassum varians*
Dactylophora nigricans		*Caulerpa cactoides*
Sphyraena novaehollandiae		*Caulerpa obscura*
Meuschenia flavolineata		*Dictyosphaeria sericea*
Meuschenia hippocrepis		*Abjohnia laetevirens*
Parascyllium variolatum		*Plocamium preissianum*
Hypoplectrodes nigrorubrum		*Sargassum heteromorphum*
Ophthalmolepis lineolatus		*Caulerpa flexilis* var. *muelleri*
Meuschenia venusta		

Table 4. Species with lowest principal eigenvector scores in DECORANA analysis. Principal eigenvector scores produced by DECORANA analysis were negatively associated with southeastern Tasmania. Species most characteristic of the Tasmanian bioprovince are indicated by asterisk.

Fishes	**Invertebrates**	**Algae**
Conger verreauxi	*Astrostole scabra**	*Macrocystis pyrifera**
Genypterus tigerinus	*Patiriella regularis**	*Xiphophora gladiata**
*Paratrachichthys trailli**	*Argobuccinium vexillum**	*Carpomitra costata*
Hippocampus abdominalis		*Caulerpa trifaria*
Phyllopteryx taeniolatus		*Hypnea ramentacea*
Neosebastes scorpaenoides		*Jeannerettia lobata*
Caesioperca lepidoptera		*Lenormandia marginata*
Apogon conspersus		*Lenormandia muelleri*
Trachurus declivis		*Dictymenia harveyana*
*Mendosoma allporti**		*Callophyllis lambertii*
*Forsterygion varium**		*Kallymenia cribrosa*
Pictiblennius tasmanianus		*Desmarestia ligulata**
Seriolella brama		
*Latris lineata**		
*Omegophora armillata**		

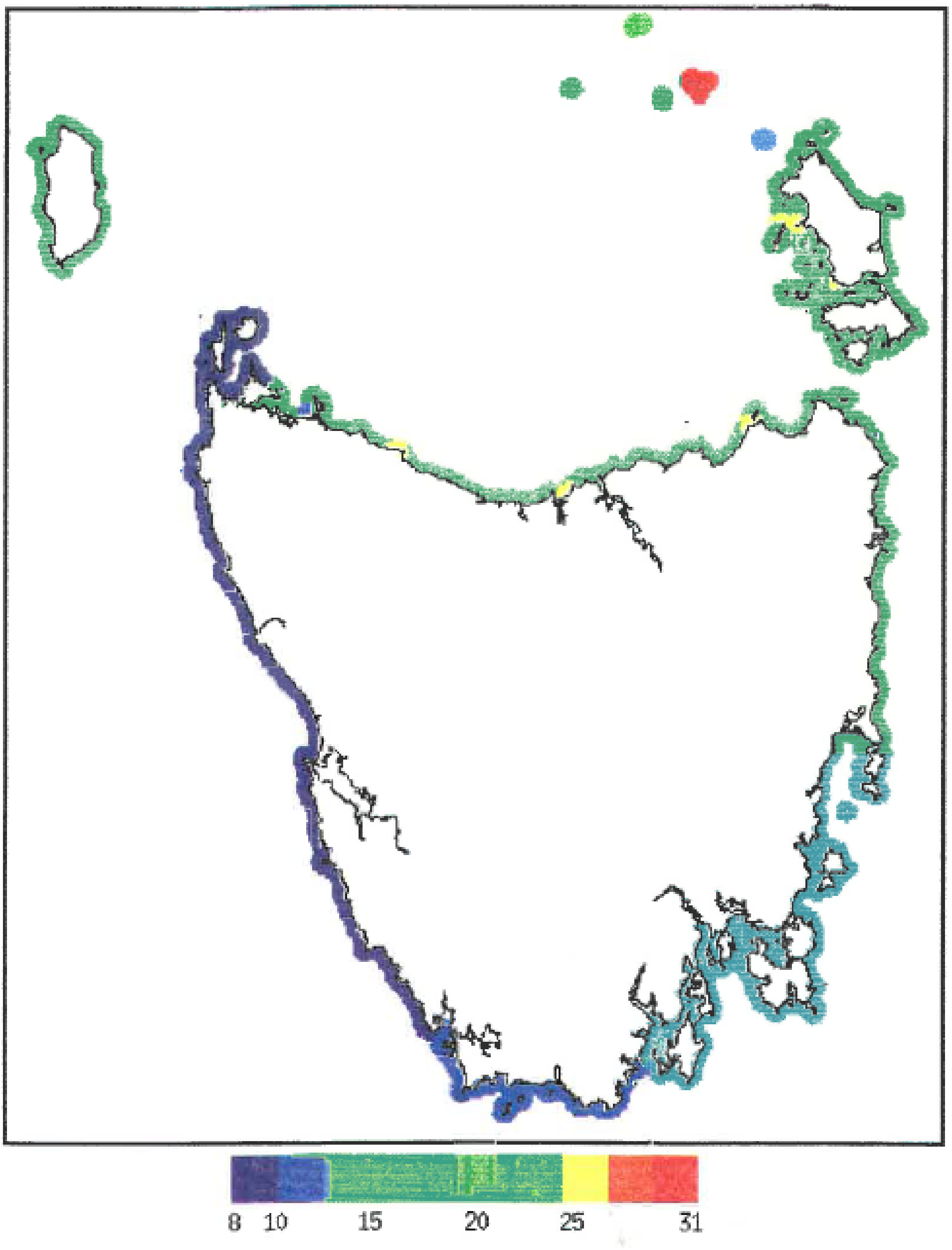

Fig. 16. Total number of recorded and interpolated fish, invertebrate and plant species found on reefs in different areas of the coast after species recorded during censuses within existing marine reserves had been removed from analysis.

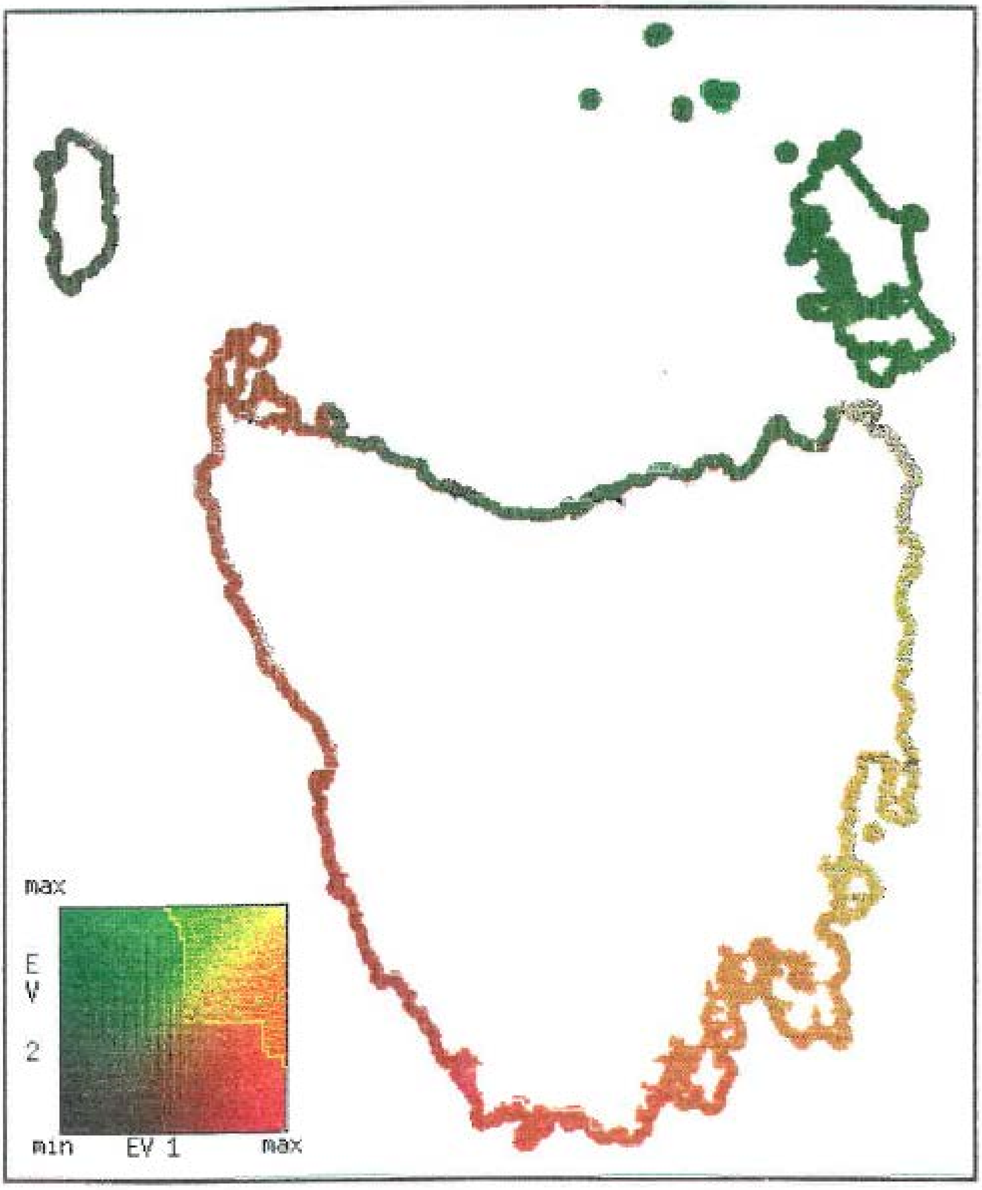

Fig. 17. Degree of similarity in reef biota along different areas of coast, as indicated by DECORANA analysis.

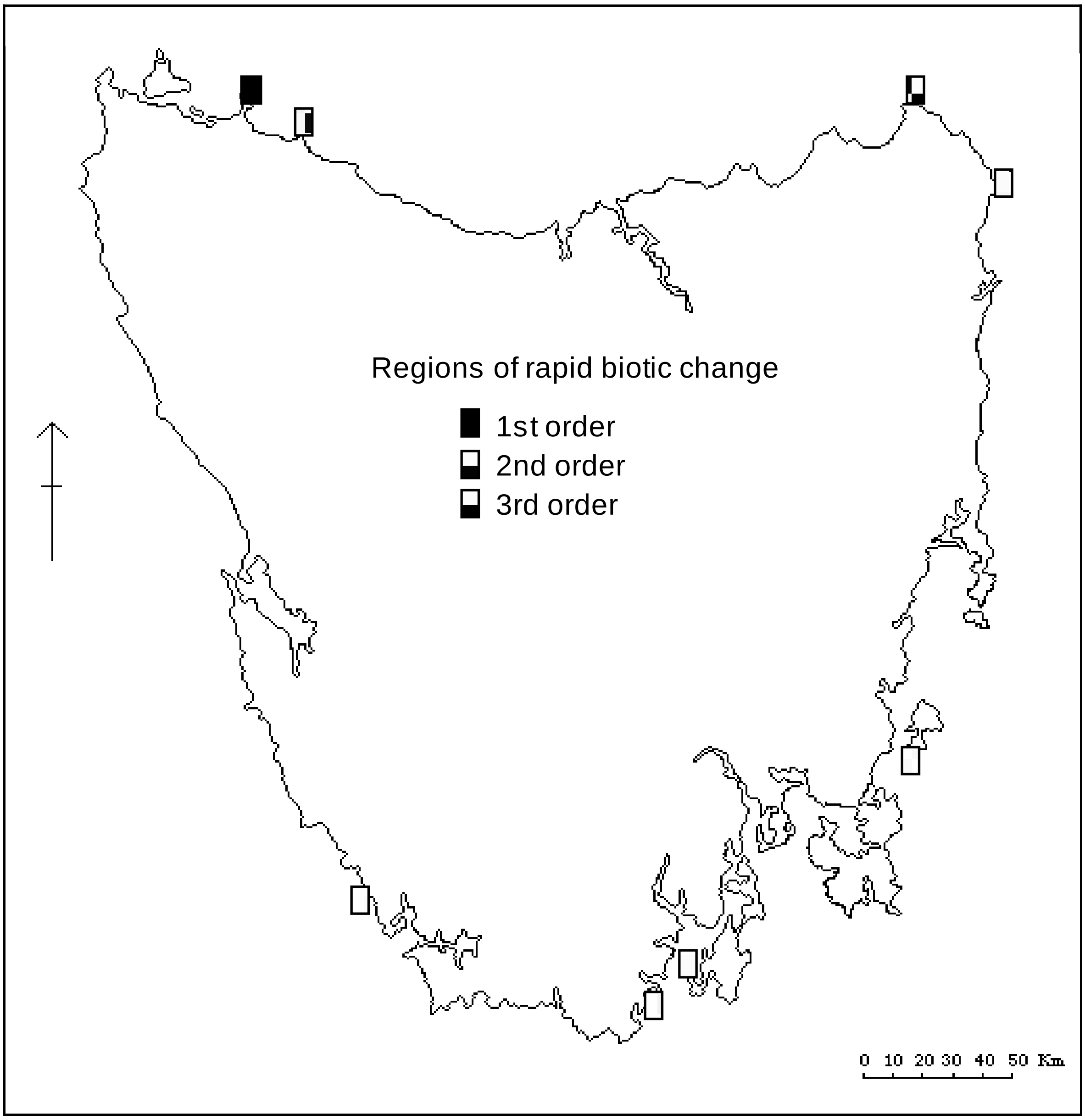

Fig. 18. Locations of major biotic change around the Tasmanian coast, as indicated by Ecotone Analysis.

DISCUSSION

BIOREGIONALISATION OF TASMANIAN COASTAL WATERS

The major separation in the reef fish, invertebrate and plant data sets was between sites in Bass Strait and those located along the eastern, southern and western Tasmanian coasts (see Figs 17 and 18). This division was less clearly defined for beach-washed shells and soft-sediment fishes than for reef plants and animals, indicating that regional patterns for soft-sediment or estuarine ecosystems may differ from patterns for reef communities.

Differences between Bass Strait ecosystems and those further south are particularly noticeable because a number of species that occur abundantly in each area are absent or rare in the other (Tables 3 and 4). The magnitude and qualitative nature of these differences indicates that the two areas lie in different biogeographical provinces (bioprovinces), which are referred to here as the Bassian and Tasmanian bioprovinces. The more traditional arrangement of Australian biogeographic provinces incorporates the Tasmanian bioprovince within the "Maugean" biogeographic province, a larger area extending from Robe (SA) around Tasmania to Eden (NSW), with the Bass Strait area comprising an overlap zone in which the Maugean bioprovince and the southern Australian "Flindersian" bioprovince overlap (Bennett and Pope, 1964; Edgar, 1984b).

Although the distinction between the Bassian and Tasmanian bioprovinces is well defined with respect to reef biota, the physical determinants that restrict species to one or the other of these provinces have yet to be fully identified. Sea surface temperature, a parameter previously considered important (Edgar, 1984b), did not adequately account for observed patterns. If summer water temperature was the primary factor influencing species distributions, then the eastern Bass Strait island sites should have separated at the primary level (see Fig. 2a), whereas if winter temperature was important then the King Island biota should have been distinctively different from that found around the rest of the Tasmania (see Fig. 2b).

Wave exposure probably has the largest influence of the distribution of biota, both at the local and regional levels. When individual census sites (200 m sections of reef) were examined, the lowest degree of similarity in reef communities was found between sheltered and exposed locations (Fig. 3).

At the larger regional scale, the differences between Bass Strait and the more southern areas of Tasmania correspond with changes in wave exposure and bathymetry. The northern Tasmanian coast shelves gradually into Bass Strait and is classed as a sheltered open or moderately exposed coast (*sensu* Bennett & Pope, 1960). The western and southern coasts have narrow shelfs and are maximally exposed because of the onshore effects of the West Wind Drift, while the eastern coast has a narrow shelf and is submaximally exposed. Along the eastern coast no large open embayment exists south of Bass Strait for 150 km until Great Oyster Bay. The presence of a few relict species more typically associated with Bass Strait in Great Oyster Bay (e.g. the seagrass *Amphibolis antarctica* and the brown alga *Cystophora monilifera*) indicates that shelter is important to at least these species, and that a number of Bassian species would probably occur along the northern east coast if sheltered open coastal conditions occurred in the area. Along the western coast, the only large marine embayment is Port Davey, 250 km south of Bass Strait.

Based on the distribution of reef plants and animals (Fig. 8), each of the two bioprovinces can be subdivided into four distinct biogeographic regions (bioregions). The Bassian bioprovince contains bioregions in the vicinity of: (i) the Kent Group (Gippsland bioregion), (ii) the eastern Bass Strait Islands other than the Kent Group (Flinders bioregion), (iii) King Island (Otway bioregion), and (iv) the northern Tasmanian coast (Boags bioregion), while the Tasmanian bioprovince contains bioregions along the western (Franklin), southern (Davey), southeastern (Bruny) and eastern (Freycinet) coasts (Fig. 19):

<u>Gippsland Bioregion</u>

The major rationale for placing the Kent Group in its own bioregion is its anomalous fish fauna (Figs 9 and 13; Table 2), presumably caused by dispersal into the area of larvae that are carried by the East Australian Current from spawning grounds in New South Wales (Last, 1979; Kuiter, 1981). The different character of subtidal reefs around the Kent Group compared to those elsewhere in Tasmania is, however, not only caused by dominant fishes that are more typically associated with New South Wales reefs (e.g. *Chromis hypselepis* and *Parma microlepis*; Edgar, 1984a), but also results from shallow (<15 m) reefs being encrusted by coralline algae and generally lacking macroalgae due to the grazing activities of aggregations of another typical New South Wales species (Andrew and Underwood, 1989), the sea urchin *Centrostephanus rodgersii*.

Because of the strong biotic relationships between the Kent Group and southern New South Wales, we consider that the Kent Group bioregion is most likely congruent with the Gippsland bioregion, a region identified in Victorian (D. Hough, pers. comm.) and New South Wales (E. Ortiz, pers. comm.) studies, which extends from Seaspray (Vic) to Twofold Bay (NSW). This supposition is, however, tentative; further investigative work is required to clarify relationships between the states. The name of this bioregion refers to the offshore Gippsland Basin.

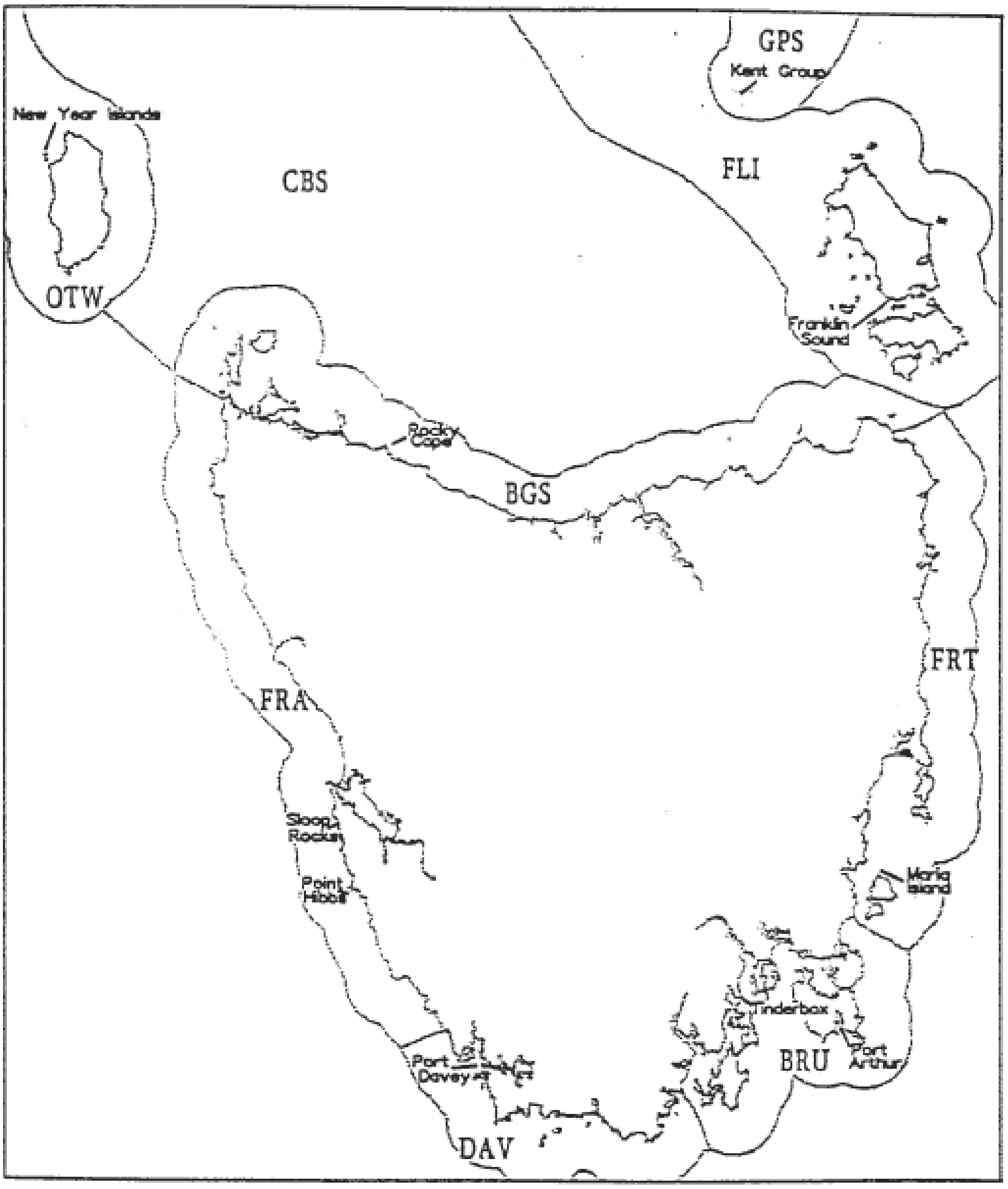

Fig. 19. Major bioregions inferred for reef biota around the Tasmanian coast, with recommended locations for representative marine reserves also shown. Bioregions are abbreviated by code as follows: Franklin, FRA; Davey, DAV; Bruny, BRU; Freycinet, FRT; Boags, BGS; Otway, OTW; Flinders, FLI; Gippsland, GPS. The central Bass Strait region, an area lacking reefs, is indicated by CBS.

Flinders Bioregion

Although the invertebrates recorded around Flinders Island differ substantially from those found off Hogan and Curtis Islands in northeastern Bass Strait (Fig. 10), we have classed these sites within a single bioregion because of the affinities in the fish and plant biotas (Figs 9 and 11), and because the interpolation technique used to identify bioregions exaggerates differences between northernmost (and southernmost) sites and those in the central Tasmanian region. Central locations will have a large number of interpolated species added to their species lists because of the presence of those species at sites either side of the location, whereas the northernmost sites have very few, if any, sites to the north and will thus have negligible interpolated species added. The overall consequence of this interpolation process is that the northernmost and southernmost sites have artificially low species counts, and those regions therefore attenuate away from central Tasmania during MDS.

Assuming that the Hogan, Curtis and Flinders Island biotas should be classed together within the one bioregion, then that region also presumably extends to Wilsons Promontory in Victoria. Physical factors (wave exposure, water temperature, bathymetry, tidal range, geological formations, etc.) do not change abruptly at the state border (Hamilton, 1994; LCC/CNR, 1994), which was defined arbitrarily by colonial authorities as the 39°12’ parallel of latitude on the map. The Flinders bioregion is named after Flinders Island and also refers to Matthew Flinders, the navigator who discovered Bass Strait.

Otway Bioregion

Another bioregion that probably overlaps state borders extends around King Island. The presence of a few typical South Australian species at King Island (e.g. the queen morwong *Nemadactylus valenciennesi*), and the concurrence between intertidal invertebrate species at King Island and Cape Otway (King, 1973; Phillips et al., 1984), indicates that the King Island bioregion probably extends to Cape Otway; if this assumption is correct then it forms part of the Otway bioregion that extends from Robe in South Australia along the western Victorian coast to Cape Otway.

Boags Bioregion

The fourth Bass Strait bioregion is a relatively homogeneous one that extends along the northern Tasmanian coastline from near Cape Portland to near Cape Grim. Pending additional evidence, we have situated the easternmost boundary of this bioregion at Tree Point (12 km southeast of Cape Portland) because this is the southernmost recorded location in Tasmania where meadows of the conspicuous seagrass *Posidonia australis* have been recorded. Swan Island, which lies 5 km offshore from Tree Point, lacks

Posidonia australis beds and possesses a reef biota intermediate between the Boags and Freycinet bioregions (Fig. 8). It has been classed within the Boags bioregion because several typical Bassian species have been recorded there (viz. the fishes *Sphyraena novaehollandiae* and *Aracana ornata*, the seastar *Plectaster decanus*, the abalone *Haliotis laevigatus*, the seagrass *Amphibolis antarctica*, and the macroalgae *Cystophora monilifera* and *Xiphophora chondrophylla* (G. Edgar, personal observations).

The location of the westernmost boundary of the Boags bioregion is not precisely known because of the lack of census work carried out in that area. This boundary presumably lies west of Three Hummock Island, where Bassian species such as *Meuschenia flavolineata, Parma victoriae* and *Aracana ornata* occur (Edgar, 1981, 1984b), and north of Green Point, the northernmost site censused during this study on the west coast. We have tentatively placed this boundary at Cape Grim, the most prominent geographical feature in the area. The name of this bioregion refers to Jimmy Boags, a historical identity well regarded throughout northern Tasmania.

<u>Franklin Bioregion</u>

A west coast bioregion extends from Cape Grim to between Brier Holme Bay and the northern headland of Port Davey (i.e., to the vicinity of Svenor Point; see Fig. 8). This bioregion is better defined than most other bioregions and is also evident in analyses using mollusc and soft-sediment fish data. Probably the most important physical factor influencing the region is the uninterrupted westward fetch and extreme wave energy impinging on the coast, with wave heights exceeding 19 m recorded in the area (Reid and Fandry, 1994). Rather than possessing characteristic plants or animals, the primary biotic characteristic of this region is its low diversity, with considerably fewer species recorded than elsewhere around the Tasmanian coast (Table 2). The name refers to the Franklin River, a major geographical feature in the area that in turn was named after John Franklin, a colonial Governor of Tasmania and maritime explorer.

<u>Davey Bioregion</u>

Closely associated with the Franklin bioregion is a southern Tasmanian bioregion that extends from near Svenor Point to near Southport, and includes the Actaeon Islands. The major features of this bioregion are an algal flora that is distinctly different to that found elsewhere (Fig. 11), and a low diversity of fish species. Although the MDS analysis using shell data apparently indicates that this bioregion should be split into two (zones 2 and 3 in Fig. 6), the separation of zone 3 (south coast) in Fig. 6 is an artefact caused by very little mollusc data having been obtained from the area.

The most prominent geomorphological feature within the Davey bioregion is Port Davey, an embayment with an unusual fauna (Edgar, 1984a), including a number of fishes, molluscs and cnidarians that have not been recorded elsewhere. The name of the bioregion refers to Port Davey, and therefore to Thomas Davey, the second colonial Governor of Tasmania.

Bruny Bioregion

The Bruny bioregion in southeastern Tasmania is the least clearly-defined of the bioregions shown in Fig. 8, and perhaps should not be separated from the Freycinet bioregion that occurs further north on the eastern Tasmanian coast. The Bruny bioregion was considered distinctive partly on the basis of differences in reef and soft-sediment fish faunas (Figs 7 and 9) and because of the ecotone identified at the southern boundary of Maria Island (Fig. 17). More importantly, this bioregion has the highest localised level of marine endemism in Tasmania, and probably Australia. Some of the larger plant, invertebrate and fish species that have not been recorded outside this bioregion are listed in Table 5. It should, however, be noted that many of the plants restricted to this area within Australia are not endemic because they also occur overseas along cool coasts; these species probably reach the region following long-distance dispersal of reproductive propagules around the Southern Ocean, so more intensive collecting may well show that they also occur in at least the southern Davey bioregion.

Table 5. Species restricted to the Bruny bioregion within Australia.

Fishes	**Invertebrates**
Brachionichthys hirsutus	*Marginaster littoralis*
Brachionichthys sp.	*Patiriella vivipara*
Forsterygion multiradiatum	*Smilasterias tasmaniae*

Macroalgae

Urospora penicilliformis (also cold temperate waters overseas)
Myrionema incommodum (also southern South America)
Gononema ramosum (also southern South America)
Scytothamnus fasciculatus (also New Zealand)
Eryhtrotrichia foliformis (also New Zealand)
Cirrulicarpus polycoelioides
Aeodes nitidissima (also New Zealand)

The name of this bioregion refers to Bruny Island, a prominent coastal feature in the area that was named after Bruni D'Entrecasteaux, the leader of a French exploring party that visited southeastern Tasmania in 1792.

Freycinet Bioregion

The northern east coast (Freycinet) bioregion is heterogeneous because a number of species, particularly fish, are present in the northern section but are absent from the south. Many of these are warm temperate species that are common in New South Wales and recruit in variable numbers in northeastern Tasmania each year, presumably because of vagaries in the positions of eddies generated from the East Australian current. Included amongst these are the fishes *Parma microlepis* and *Girella elevata*, the sea urchin *Centrostephanus rodgersii*, the barnacle *Austromegabalanus nigrescens* and the prawn *Penaeus plebejus*. Future investigation may show that the northeastern section warrants separation from the central east coast (see Fig. 9).

The name of this bioregion refers to the most prominent coastal feature in the area, Freycinet Peninsula, and hence to Louis de Freycinet, an officer in the French exploring party led by Baudin that visited eastern Tasmania in 1802.

RECOMMENDATIONS FOR A TASMANIAN MARINE RESERVE SYSTEM

The regionalisation and recommendations for marine reserves described here are largely based on analyses pertaining to reef plants and animals. This bias was intentional as coastal reefs are the marine habitats most affected by human activity in Tasmania and consequently the most in need of protection. While other marine habitats are locally threatened, for example soft sediment habitats by dredging for scallops and clams, recreational and inshore commercial fishing activity is presently centred on shallow reefs. A variety of reef species at several trophic levels, including carnivorous fishes, herbivorous abalone, periwinkles and sea urchins, and omnivorous rock lobsters, are targeted by divers and by fishers using gillnets, pots and traps.

However, even more threatened than any marine community is the biota found in estuaries. Most Tasmanian estuarine ecosystems, including virtually all along the eastern and northern coasts, are badly degraded by pollution, siltation, nutrification and shore development. Although a number of nature reserves have boundaries that encompass estuarine waters and include protection for the habitat itself, no component of the biota (i.e. fishes, invertebrates or plants) is fully protected within any estuary around the State. While gillnetting is now prohibited in most Tasmanian estuaries, other methods of fish capture such as angling and spearing, and the taking of shellfish, are allowed. Survey work is urgently needed to identify the most appropriate sites for estuarine protected areas.

The most pressing conservation need as far as marine habitats are concerned is for a representative marine reserve to be declared in the Bass Strait region. Reef species present in northern Tasmania include a large proportion of species that do no occur south of Bass Strait and are not protected within any reserve at present (see Fig. 16; Table 3). A marine reserve at the Kent Group would have highest conservation value because of the presence of a number of species in this area that do not occur along the northern Bass Strait coast.

While the declaration of a marine reserve in the Bass Strait region is needed as a matter of immediate urgency, the recommended longer term strategy is to declare at least one representative marine reserve within each of the Tasmanian bioregions. Given that nearly all of the more valuable Tasmanian marine resources are fully exploited or overexploited at present (Kailola *et al.*, 1993), that benefits accruing from a representative reserve system are almost universally recognised as far as terrestrial ecosystems are concerned (Margules *et al.*, 1988), and that the value of an integrated marine reserve system is now advocated in virtually all recent reports describing conservation priorities in the marine environment (see, e.g., Ballantine, 1991; LCC, 1995; Zann, L.P., 1995), a representative Tasmanian marine reserve system is clearly desirable.

The selection of the most appropriate marine reserve site within each bioregion requires consideration of biological, physical, social and economic considerations. The emphasis during the initial selection process, which is described here, has been on the biological and environmental factors, with the social and economic factors requiring emphasis during the public consultation stage. The rationale for this approach is that if social and economic factors are preeminent at an early stage, then an *ad hoc* system of reserves will be produced that may have negligible conservation value (Ray and McCormick-Ray, 1992). By contrast, the boundaries of representative marine reserves can be modified while still retaining the overall conservation value of the reserve system.

Each of the following potential marine reserve sites is recommended for protection because, on the basis of available data, it is the location within the particular bioregion that conforms most closely to the ideal reserve. Ideally, the reserve should possess (i) a large range of habitats (sheltered to maximally exposed; shallow to deep; reef, soft-sediment, seagrass), (ii) protected adjacent shoreline and watershed, (iii) a low level of recreational and commercial fishing, (iv) an absence of other anthropogenic impacts, and (v) a total coastal length in excess of 10 km. This last criterion was included because preliminary information on changes in animal densities obtained from the Maria Island, Tinderbox, Ninepin Point and Governor Island Marine Reserves indicated that densities of heavily targeted species have increased little within the three smaller reserves over the two year period following declaration (G. Edgar and N. Barrett, unpublished data). Reserves with a total coastal length of at least 10 km are therefore probably necessary to fulfil conservation objectives. It should be emphasised that the recommendations described below may require modification in the light of future work.

Gippsland bioregion

We support recommendations described previously for a marine reserve to be declared around Deal, Dover and Erith Islands (Edgar, 1984a). The boundaries for this marine reserve are best located as described in the original proposal in order to maximise the diversity of habitats contained within the reserve. The recommended area includes seagrass, sand and reef habitat ranging between sheltered and submaximally exposed coasts.

Flinders bioregion

Inadequate survey work has been conducted to precisely determine the optimum site for a marine reserve within the Flinders bioregion. However, the best location is likely to be at the entrance to Franklin Sound because that area contains the greatest range of habitats, including sand and reef habitats in both shallow and deep water, and extensive *Posidonia australis* and *Amphibolis antarctica* seagrass beds. A high biodiversity was also recorded in this area during the 1980 surveys (Edgar, 1981). Given the advantages conferred on a marine reserve when located adjacent to a National Park, we tentatively recommend that a marine reserve be declared in southwestern Flinders Island within the area from Badger Corner to Trousers Point, and extending for 1 km offshore. Survey work should be undertaken to determine whether a subset of this area is sufficient.

Otway bioregion

The most appropriate location for a marine reserve in the Otway bioregion is the area surrounding Christmas and New Year Islands off the northwestern coast of King Island. This location contains the greatest diversity of habitats in the vicinity of King Island, including extensive seagrass beds, and had the greatest biodiversity amongst sites surveyed around King Island in this study (Appendix 1). A number of reef species occurred abundantly in this area that were not found elsewhere around King Island and had not been recorded from Tasmanian waters prior to the present surveys (e.g. *Nepanthia troughtoni* and *Plocamium preissianum*).

Boags bioregion

A marine reserve extending from Rocky Cape to Boat Harbour has been previously recommended within the Boags bioregion (Edgar, 1981). This location is exceptional and remains the preferred option due to the diversity of habitats, high species diversity, relatively low level of anthropogenic disturbance, and high recreational value to divers. The most diverse and scenically attractive habitats occur at Rocky Cape and just west of Boat Harbour; it is important that both these areas be protected, so we recommend that the boundaries defined in the original proposal be used.

Franklin bioregion

The Franklin bioregion is poorly surveyed, so it is perhaps premature to identify the optimum marine reserve site within this area. Amongst the sites examined during reef censuses, the most appropriate potential marine reserve location was the vicinity of Sloop Rocks (south of the entrance to Macquarie Harbour). Reefs in the northern half of the bioregion generally submerged under sand in relatively shallow water and the reef biota was affected by sand scouring, so this northern area is unlikely to contain the best marine reserve location. We therefore tentatively recommend that the area from Dunes Creek to Gorge Point (including offshore Sloop Rocks), a location that contains deep as well as shallow reefs and some shelter to the prevailing westerly swells, be protected as a marine reserve. The environment around Point Hibbs has not been examined but includes habitats encompassing a wider range of wave exposure, so requires investigation as it may prove a more appropriate marine reserve site.

Davey bioregion

The outstanding potential marine reserve location within the Davey bioregion is Port Davey itself and adjacent Bathurst Channel and Bathurst Harbour. This location contains sites that are representative of the Davey bioregion (at the entrance to Port Davey) as well as sites that are unique (Bathurst Channel; see Edgar, 1984a), and includes a number of species not recorded elsewhere. The seabed habitat and waters in this area are already protected within the Southwest National Park. We recommend that marine and estuarine plants and animals within the National Park boundaries also be protected to create a true marine reserve.

Bruny bioregion

Two small marine reserves already exist in the Bruny bioregion, at Tinderbox and Ninepin Point. These reserves were declared for recreational and scientific reasons, respectively. Because of their small size, neither reserve can be considered to fulfil the conservation function required of a representative marine reserve. We therefore recommend that the Tinderbox marine reserve be extended for 1 km offshore and north along the coast to Lucas Point, or an alternative site is considered at Port Arthur in the area extending from Carnarvon Bay to Remarkable Cave and including the Isle of the Dead. The Port Arthur location is preferred on biological grounds because of the high local species diversity (Appendix 1) and greater range of habitats compared to Tinderbox. Closure of this area to fishing would, however, affect more fishers than an extension of the existing reserve at Tinderbox.

Freycinet bioregion

Although a large marine reserve exists at Maria Island, the conservation value of this reserve is much less than could be achieved if restrictions on fishing were generally applied within it. Of the area along the northern and northwestern coast of Maria Island initially recommended for protection (Edgar, 1981), the southernmost third containing extensive sheltered habitat was excluded from the reserve, while the northernmost third was included but with no protection given to the biota. Plants and animals are therefore fully protected only along the northeastern coastline from Cape Boullanger to Return Point, a relatively homogeneous section of coast that is moderately exposed throughout its length and contains only two rock strata (dolerite and sandstone). The extent of reefs within this protected zone is also very limited because rock submerges under sand in relatively shallow depths (<8 m). The non-protected northern zone of the Maria Island Marine Reserve, on the other hand, contains extensive reef that extends to 25 m depth and is formed from several different geological formations (limestone, dolerite and siltstone).

Given that the range of biological communities protected within the marine reserve would more than double if fishing was prohibited within the northern section, and that it is counter productive to allow unrestricted setting of gillnets within a marine reserve, a procedure banned in other Australian states, we recommend that fishing be prohibited throughout the existing Maria Island Marine Reserve. We also recommend that the boundary of the reserve be extended southwards to include seagrass habitat in Booming Bay and sheltered habitat in Chinamans Bay. This southern section was excised from the original proposal by the Marine Reserves Working Party on the condition that an equivalent area of sheltered coastal habitat be located in the region and reserved. No equivalent area of sheltered coastal habitat that includes extensive seagrass beds has been found.

Macquarie bioregion

While not investigated nor described in this report, the marine biota associated with subantarctic Macquarie Island differs almost completely from that found elsewhere in Tasmanian waters, and requires protection within a Tasmanian marine reserve system. A detailed description of the Macquarie Island environment and recommendations for a marine reserve surrounding the island have been made by Scott (1994). These proposals should be implemented as soon as possible.

Restrictions within recommended marine reserves

Within all the potential marine reserve areas described above, we recommend that exploitative activities be excluded using similar regulations as are applied within existing marine reserves. Without a general prohibition on fishing and other exploitative activities, the benefits accruing from the reserve system are likely to be significantly compromised.

The problems that arise when some activities (e.g. angling) are allowed and others restricted within marine reserves include difficulties in policing, diminution of the value of the area for scientific research, and, most importantly, the flow-on effects that the removal of one important species can cause to the whole ecosystem. The consequences of rock lobster, abalone, finfish, sea urchin or seaweed removal to other marine species in Tasmania are presently unknown, but are probably substantial given that these organisms all interact and that various studies indicate that the removal of key species can alter ecosystem function. For example, the exploitation of rock lobsters was found to completely alter the invertebrate community associated with South African reefs (Barkai and Branch, 1988). In Australian and New Zealand studies, the removal of wrasses has been found to increase the survival of juvenile sea urchins (Andrew and Choat, 1982), with high numbers of sea urchins denuding reefs of seaweed (Choat and Andrew, 1986; Fletcher, 1987; Andrew and Underwood, 1993) and possibly affecting densities of rock lobsters (Andrew and MacDiarmid, 1991). The presence of seaweed in turn affects the densities of fishes (Choat and Ayling, 1987; Jones, 1992).

Until ecological processes on Tasmanian reefs are better understood and the effects of fishing predictable, no exploitation should be allowed within the core areas of the marine reserves recommended here. Buffer areas where types of exploitation are allowed that do not interfere with the habitat should, however, be considered in the waters immediately adjacent to marine reserves (see Kenchington and Agarty, 1990).

FUTURE PRIORITIES

With respect to conserving the marine flora and fauna of Tasmania, the most important needs are (i) to provide the public with information outlining the value of a representative system of marine reserves within the state, (ii) to form an interdepartmental working group to facilitate the process, and (iii) to publicise a tentative timetable listing the dates at which various goals are to be achieved. Hopefully, these processes will be expedited by distributing this report widely amongst commercial and recreational fishers, divers, local councils, conservation groups and other users of the coast. The support of interested parties is critical to the declaration of any reserve; their active participation is also needed to identify the most appropriate boundaries for reserves within each bioregion.

Priorities for future research, in order of importance, are:

1. The flora and fauna of estuaries around Tasmania should be investigated using standardised procedures in order to produce a regionalisation similar to that described for reef species. Because virtually all estuaries along the northern and eastern Tasmania coasts are badly degraded (Rees, 1995), representative estuaries that have remained relatively pristine within each bioregion need to be identified and protected as a matter of urgency. Estuarine information was partly included in analyses of soft-sediment fishes and beach-washed shells here, but patterns were obscured by data obtained from marine habitats. Given the differences between regional patterns shown in Figs 5, 6 and 7, estuarine bioregions are likely to be quite different to those described using reef data. Communities of plants and animals have not yet been protected within any estuary in Tasmania.

2. Further reef survey work should be conducted in the northwestern region (particularly around Three Hummock Island and Hunter Island), along the western Tasmanian coast near Point Hibbs, and in Franklin Sound in the Furneaux Group. The gap in the data base around Three Hummock Island prevented the location where the Bassian bioprovince merges into the Tasmanian bioprovince from being precisely identified. The lack of reef data from the Tasmanian west coast prevented us from making a clear recommendation for a marine reserve site in that bioregion. Franklin Sound requires further investigation because the area encompasses a great range in habitat diversity, indicating that it is likely to be the most suitable location in the bioregion for a marine reserve; however, no recent survey work has been conducted in the area.

3. Survey work should be undertaken in Victoria and Tasmania using comparable methods to determine whether King Island has a similar biota to the Otway coast, Flinders Island has a similar biota to Wilsons Promontory, and the Kent Group has a similar biota to the Gippsland coast.

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Appendix 1. Total number of species of fishes, invertebrates and plants at reef sites censused, with latitude and longitude of sites also shown. *taxa not quantitatively surveyed.

Site	Depth (m)	Latitude	Longitude	Date	Fish	Inverts	Plants	Total
Franklin bioregion								
Cape Sorell (midway)	10	42.196	145.184	11-May-94	8	5	16	29
Green Point	10	40.900	144.650	16-Apr-94	7	11	23	41
West Point	5	40.935	144.616	15-Apr-94	3	10	14	27
Cape Sorell (midway)	5	42.196	145.184	11-May-94	11	6	11	28
Cape Sorell light	5	42.197	145.168	9-May-94	8	7	11	26
Cape Sorrel tip	10	42.197	145.164	10-May-94	5	9	11	25
Breakwater	5	42.201	145.199	11-May-94	5	7	10	22
South Cape Sorell	5	42.216	145.187	9-Jun-94	2	7	7	16
Sloop Point	10	42.313	145.193	10-Jun-94	7	5	14	26
Low Rocky Point	10	42.986	145.509	21-Jun-94	4	9	18	31
Brier Holme Bay	10	43.115	145.712	21-Jun-94	1	6	17	24
Bluff Hill Point	5	41.008	144.610	15-Apr-94	4	8	18	30
Davey bioregion								
Rough Bay	5	43.311	145.849	5-May-94	5	5	19	29
Saddle Bight	5	43.305	145.897	4-Apr-93	6	8	22	36
Big Caroline Rock	10	43.365	145.917	5-Apr-93	6	12	14	32
Breaksea Island	5	43.334	145.967	2-Apr-93	3	11	16	30
Mutton Bird Island	5	43.418	145.971	5-May-94	7	4	35	46
Sarah Island	5	43.332	145.994	3-Apr-93	10	16	7	33
Window Pane Bay	10	43.465	146.012	23-Jun-94	1	4	22	27
New Harbour	10	43.522	146.146	23-Jun-94	6	7	21	34
Maatsuyker Island	10	43.646	146.282	24-Jun-94	5	4	20	29
De Witt Island	10	43.593	146.376	24-Jun-94	16	11	18	45
West of Surprise Bay	5	43.584	146.641	31-Mar-94	9	5	27	41
Shoemaker Bay	10	43.602	146.666	31-Mar-94	9	7	23	39
South Cape Site 1	10	43.631	146.708	29-Mar-94	9	5	22	36
South Cape Site 2	10	43.629	146.724	29-Mar-94	7	5	15	27
South Cape Rivulet	10	43.608	146.783	29-Mar-94	10	*	*	
South East Cape (north)	10	43.643	146.831	30-Mar-94	10	6	17	33
Whale Head	5	43.636	146.872	28-Mar-94	11	5	13	29
Whale Head	10	43.636	146.872	28-Mar-94	9	5	26	40
Actaeon Island	5	43.527	146.996	9-Mar-94	9	6	23	38
Actaeon Island	10	43.527	146.996	9-Mar-94	9	4	32	45
Schooner Point	5	43.341	146.007	3-Apr-93	14	18	0	32
Little Woody Island	5	43.341	146.049	5-Apr-93	4	10	0	14
Joan Point	5	43.343	146.085	7-Apr-93	4	10	0	14
Eve Point	5	43.347	146.099	7-Apr-93	3	14	0	17
Celery Top Island	5	43.367	146.140	6-Apr-93	2	2	0	4

Appendix 1 (cont.) Total number of species of fishes, invertebrates and plants at reef sites censused, with latitude and longitude of sites also shown.

Site	Depth (m)	Latitude	Longitude	Date	Fish	Inverts	Plants	Total
Bruny bioregion								
Two Mile Beach	5	42.871	147.957	17-Feb-94	13	19	16	48
Lagoon Bay	5	42.885	147.973	17-Feb-94	10	10	27	47
Deep Glen Bay	5	42.974	147.986	24-Jan-94	5	4	28	37
Rockslide	5	42.998	147.954	24-Jan-94	12	4	22	38
Lucas Point	5	43.039	147.338	16-Apr-92	19	14	21	54
Betsy Island	5	43.049	147.486	1-Feb-94	9	15	20	44
Piersons Point	5	43.053	147.343	11-Mar-92	21	12	18	51
Central	5	43.060	147.330	8-Apr-92	21	17	17	55
Iron Pot	5	43.060	147.415	2-Feb-94	14	18	11	43
Waterfall Bay	5	43.062	147.948	25-Jan-94	5	12	20	37
Waterfall Bay	10	43.062	147.948	25-Jan-94	11	12	22	45
Dennes Point	5	43.065	147.351	1-May-92	18	16	17	51
One Tree Point	5	43.130	147.400	28-Jan-94	13	18	27	58
Fortescue Bay	5	43.132	147.959	16-Jun-94	11	11	17	39
Fortescue Bay	10	43.132	147.959	16-Jun-94	9	14	19	42
Port Arthur	5	43.139	147.865	15-Jun-94	19	15	21	55
Port Arthur	10	43.139	147.865	15-Jun-94	14	13	24	51
Roberts Point	5	43.149	147.280	3-Feb-94	17	7	9	33
Isle of the Dead	5	43.150	147.868	16-Feb-94	19	15	29	63
Isle of the Dead	10	43.150	147.868	16-Feb-94	19	10	33	62
Variety Bay	5	43.189	147.411	28-Jan-94	8	14	30	52
Cape Queen Elizabeth	5	43.255	147.424	10-Feb-94	11	10	20	41
Cape Queen Elizabeth	10	43.255	147.424	10-Feb-94	17	14	23	54
Charlotte Cove Light	5	43.274	147.141	10-Mar-92	13	7	23	43
Ninepin Point	5	43.286	147.166	10-Mar-92	19	11	18	48
Arch Island	5	43.288	147.178	11-Feb-94	15	15	26	56
Huon Island	5	43.296	147.140	15-Apr-92	18	8	23	49
Zuidpool Rock	10	43.333	147.175	15-Mar-94	17	9	25	51
Little Penguin Point	5	43.356	147.177	15-Mar-94	17	12	29	58

Appendix 1 (cont.) Total number of species of fishes, invertebrates and plants at reef sites censused, with latitude and longitude of sites also shown.

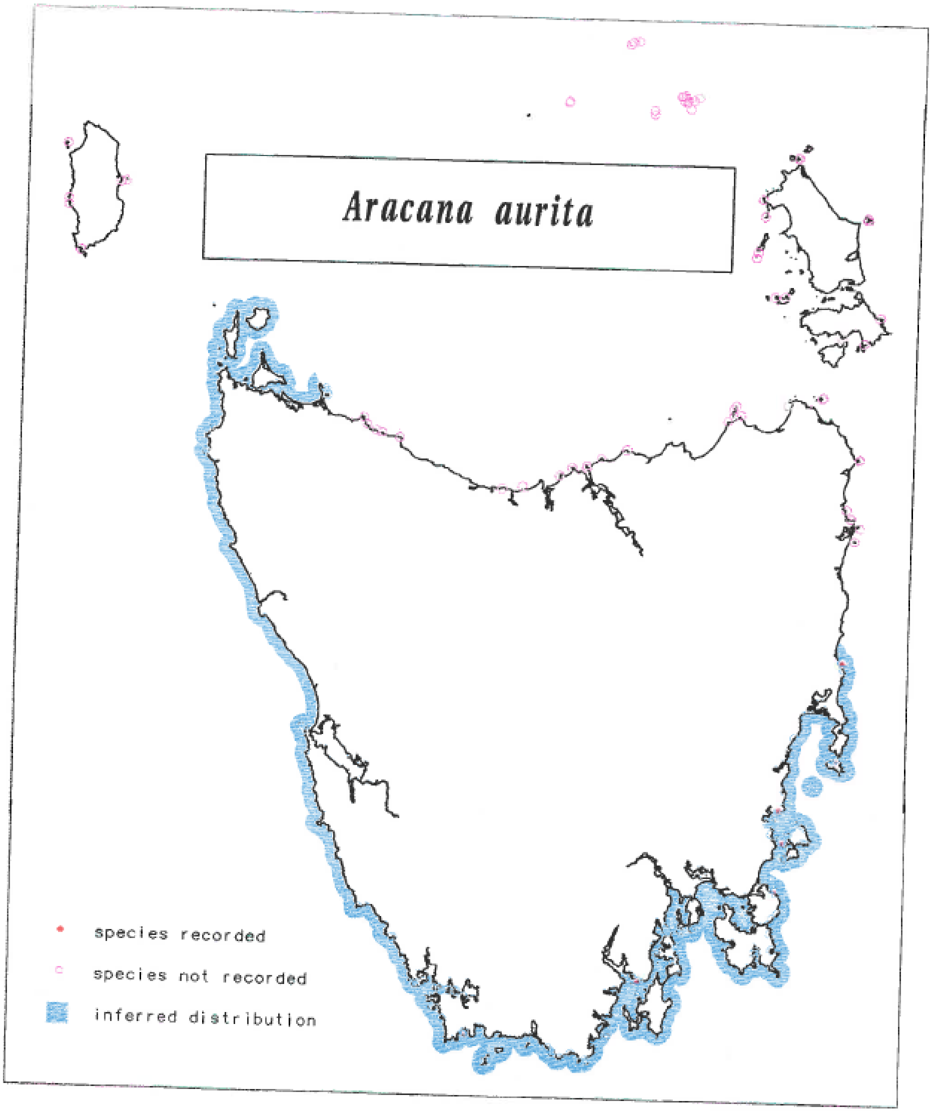
Site	Depth (m)	Latitude	Longitude	Date	Fish	Inverts	Plants	Total
Freycinet bioregion								
Fossil Cliffs	5	42.575	148.080	16-Mar-92	15	9	7	31
Fossil Cliffs	10	42.575	148.080	3-May-92	15	11	15	41
Ile du Nord	5	42.565	148.066	26-Mar-92	19	17	25	61
Whalers Cove	5	42.666	148.117	5-May-92	17	17	19	53
Northeast siltstone	10	42.592	148.123	18-Mar-92	17	7	14	38
Point Lesueur	5	42.663	148.005	2-Apr-92	16	12	18	46
Green Bluff	5	42.732	148.010	6-May-92	25	16	25	66
Ile des Phoques	10	42.416	148.161	7-May-92	16	12	12	40
Bunker Bay	5	42.665	148.135	30-May-93	10	8	15	33
Fossil Cliffs (east)	5	42.584	148.106	4-Jun-93	16	14	28	58
Darlington North	5	42.578	148.061	19-Mar-92	23	12	27	62
Painted Cliffs South	5	42.601	148.047	2-Jun-93	23	14	19	56
Painted Cliffs North	5	42.595	148.049	17-Mar-92	12	11	20	43
Return Point	5	42.631	148.022	2-Jun-93	21	10	23	54
Magistrates Point North	5	42.584	148.053	23-Mar-92	19	12	25	56
Magistrates Point South	5	42.588	148.051	3-Apr-92	15	8	31	54
Cape Bougainville	5	42.508	148.002	25-Mar-92	19	15	14	48
Point Holme Lookout	5	42.554	147.946	25-Mar-92	19	17	18	54
Lachlan Island	5	42.645	147.979	24-Mar-92	19	14	9	42
Spring Beach	5	42.586	147.914	7-Apr-92	23	20	21	64
Okehampton Bay	5	42.525	147.968	9-Apr-92	18	17	21	56
Rheban	5	42.630	147.934	12-Aug-92	11	14	8	33
Grindstone Bay	5	42.440	148.003	31-May-93	8	9	15	32
Southeast Governor Island	5	41.876	148.313	18-May-93	8	9	14	31
Southeast Governor Island	10	41.876	148.313	18-May-93	19	18	9	46
North Governor Island	5	41.872	148.311	20-May-93	14	8	8	30
North Governor Island	10	41.872	148.311	29-Apr-94	18	13	4	35
Blow Hole	5	41.881	148.308	19-May-93	14	5	11	30
Blow Hole	10	41.881	148.308	19-May-93	13	13	16	42
Halfway Point	5	41.905	148.315	19-May-93	10	15	3	28
Waubs Bay	5	41.872	148.302	20-May-93	14	18	12	44
Waubs Bay	10	41.872	148.302	27-Apr-94	18	15	16	49
Schouten Island 1	5	42.311	148.234	30-Sep-92	6	10	4	20
Schouten Island 2	5	42.295	148.257	30-Sep-92	6	10	14	30
Schouten Island 3	5	42.299	148.275	17-May-93	26	14	21	61
Northwest Schouten Island	5	42.298	148.287	28-Jun-94	17	15	23	55
St Helens Island	5	41.346	148.338	1-Mar-94	12	12	5	29
St Helens Rocks	5	41.289	148.367	1-Mar-94	11	14	10	35
Gardens Rocks	5	41.211	148.289	2-Mar-94	11	11	19	41
Gardens Rocks	10	41.211	148.289	2-Mar-94	11	8	25	44

Appendix 1 (cont.) Total number of species of fishes, invertebrates and plants at reef sites censused, with latitude and longitude of sites also shown. *taxa not quantitatively surveyed.

Site	Depth (m)	Latitude	Longitude	Date	Fish	Inverts	Plants	Total
Freycinet bioregion								
Binalong Bay	5	41.250	148.313	2-Mar-94	17	14	29	60
Eddystone Point (south)	5	40.995	148.349	3-Mar-94	8	6	11	25
Eddystone Point (south)	10	40.995	148.349	3-Mar-94	14	12	24	50
Eddystone Point (north)	5	40.991	148.345	3-Mar-94	10	4	13	27
Kelvadon Point	5	42.210	148.045	29-Apr-94	18	11	11	40
Boags bioregion								
Waterhouse Island (central)	5	40.798	147.625	23-Apr-92	20	11	28	59
Waterhouse Island (north)	5	40.780	147.640	23-Apr-92	18	*	*	
Little Waterhouse Island	5	40.824	147.627	24-Apr-92	20	14	20	54
Waterhouse Point	5	40.821	147.669	24-Apr-92	21	*	*	
North Croppies Point	5	40.850	147.593	25-Apr-92	18	16	16	50
Cape Portland	5	40.764	147.937	26-Apr-92	9	14	19	42
Anniversary Point	5	40.892	145.535	23-May-92	20	15	20	55
Sisters Rocks	5	40.917	145.587	23-May-92	20	15	21	56
Boat Harbour	5	40.926	145.618	24-May-92	19	15	19	53
Table Cape	5	40.945	145.719	24-May-92	29	13	16	58
Rocky Cape	5	40.860	145.515	25-May-92	23	15	21	59
Stony Head	5	40.981	147.021	13-Apr-94	20	8	17	45
Don Heads	5	41.158	146.309	14-Apr-94	13	9	19	41
Horseshoe Reef	5	41.147	146.423	14-Apr-94	12	10	22	44
West of Nut	5	40.742	145.297	17-Apr-94	11	15	22	48
Nut	5	40.768	145.307	17-Apr-94	27	14	21	62
Swan Island light	5	40.734	148.126	6-Jun-94	8	11	20	39
Swan Island	5	40.737	148.122	6-Jun-94	8	17	13	38
Barrel Rock	5	41.067	146.790	19-Oct-94	18	10	27	55
Low Head	5	41.055	146.788	11-Apr-94	11	7	18	36
Badger Head	5	41.101	146.641	12-Apr-94	14	8	24	46
West Head	5	41.064	146.708	12-Apr-94	7	9	15	31
Otway bioregion								
New Year Island	5	39.667	143.832	15-May-92	18	13	25	56
Johnsons Rock	5	39.903	143.832	17-May-92	7	5	21	33
Blencathra	5	39.933	143.834	17-May-92	4	*	*	
Surprise Bay	5	40.131	143.900	16-May-92	8	11	19	38
Blow Hole	5	39.837	144.132	14-May-92	13	9	18	40
Councellor Island	5	39.833	144.159	14-May-92	12	17	28	57

Appendix 1 (cont.) Total number of species of fishes, invertebrates and plants at reef sites censused, with latitude and longitude of sites also shown.

Site	Depth (m)	Latitude	Longitude	Date	Fish	Inverts	Plants	Total
Flinders bioregion								
East Island	5	39.215	147.020	19-Jun-92	15	10	21	46
Hogan Island (north beach)	5	39.216	146.991	19-Jun-92	20	9	21	50
Hogan Island (south beach)	5	39.221	146.991	18-Jun-92	18	8	26	52
Hogan Island (Tunnel Beach)	5	39.228	146.977	18-Jun-92	15	7	19	41
Curtis Island (mid southeast)	5	39.477	146.647	17-Jun-92	14	6	11	31
Curtis Island (southwest)	5	39.482	146.643	17-Jun-92	18	11	10	39
Judgement Rocks	5	39.508	147.126	22-Jun-92	4	9	19	32
South West Island	5	39.526	147.129	22-Jun-92	11	12	19	42
Inner Sister East	5	39.696	147.938	4-Jun-94	6	8	3	17
Inner Sister Passage	5	39.703	147.938	4-Jun-94	12	13	18	43
Flinders Island (northwest)	5	39.884	147.751	3-Jun-94	8	13	19	40
Babel Island	5	39.946	148.339	5-Jun-94	10	17	15	42
Babel Island	5	39.954	148.346	5-Jun-94	14	8	8	30
South Pascoe Island	5	39.957	147.763	5-Jun-94	6	12	22	40
Prime Seal Island	5	40.112	147.730	5-Apr-94	20	8	29	57
Low Islets	5	40.137	147.723	5-Apr-94	22	11	24	57
Badger Island West	5	40.302	147.837	2-Jun-94	17	8	25	50
Cape Barren	5	40.374	148.430	1-Jun-94	6	11	24	41
Sloping Point	5	40.468	148.226	16-Jun-92	11	16	23	50
Passage Point	5	40.491	148.341	16-Jun-92	12	14	24	50
Badger Island	5	40.302	147.894	2-Jun-94	15	10	26	51
Gippsland bioregion								
Erith Island (north west)	5	39.445	147.276	24-Jun-92	17	8	10	35
Erith Island (north)	5	39.445	147.284	24-Jun-92	23	8	28	59
Dover Island isthmus	5	39.466	147.293	21-Jun-92	28	11	14	53
Erith Island north east	5	39.442	147.297	20-Jun-92	16	12	21	49
Erith Island (Murray Pass)	5	39.449	147.299	25-Jun-92	25	12	19	56
Deal Island (jetty bay)	5	39.472	147.310	20-Jun-92	25	14	19	58
Deal Island (Murray Pass)	5	39.462	147.314	25-Jun-92	27	11	19	57
Karatine Bay	5	39.498	147.330	23-Jun-92	34	11	10	55
Deal Island (north east)	5	39.461	147.346	21-Jun-92	22	14	23	59
North East Island	5	39.449	147.376	23-Jun-92	17	9	7	33



Appendix 2. An example of the output produced by GIS. The interpolated distribution of the fish *Aracana aurita*..

Figure captions

Fig. 1. Locations of reef sites around Tasmania at which plants, macroinvertebrates and fishes have been censused. The locations of the 17 zones into which the Tasmania coastline was initially subdivided are also shown. Zone 13 was separated into two subzones (13 and 13*) in shell and beach fish analyses.

Fig. 2a. Mean February sea surface temperatures recorded in the Tasmanian region between 1989 and 1992.

Fig. 2b. Mean July sea surface temperatures recorded in the Tasmanian region between 1989 and 1992.

Fig. 3. Results of MDS using presence/absence data for plants, invertebrates and fishes recorded at 5 m depth reef sites. Sites in the northernmost (Curtis Island, Hogan Island and Kent Group) and southernmost (southern and southwestern Tasmanian) regions are distinguished, as are the most sheltered and exposed sites. Sheltered sites were identified by the presence the alga *Cystophora retroflexa*, a species that occurs abundantly only in calm-water habitats (Edgar, 1983), and exposed sites by the presence of the bull "kelp" *Durvillaea potatorum*, a plant that dominates sites with high levels of wave exposure (Edgar, 1984b).

Fig. 4. Results of MDS using presence/absence data for plants, invertebrates and fishes recorded within the 17 zones shown in Fig. 1.

Fig. 5. Results of MDS using recorded and interpolated data on the distribution of plants, invertebrates and fishes within the 17 zones shown in Fig. 1.

Fig. 6. Results of MDS using recorded and interpolated data on the distribution of beach-washed shells within 14 zones (shown in Fig. 1). Zone 13 (western north coast) has been divided into two, with the area denoted by 13* extending west of Port Latta. No data were collected from zones 9, 16 and 17.

Fig. 7. Results of MDS using recorded and interpolated data on the distribution of soft-sediment fishes within 13 zones (shown in Fig. 1). Zone 13 (western north coast) has been divided into two, with the area denoted by 13* extending west of Port Latta. No data were collected from zones 3, 9, 16 and 17.

Fig. 8. Results of MDS using recorded and interpolated data on the distribution of

reef biota at investigated sites. Sites often overlap, in which case only one data point is shown. Individual sites are indicated by zone codes (see Fig. 1), and are placed into bioregional groupings. Anomalous sites are as follows: 2*, Brier Holme Bay and Low Rocky Point (overlapping sites); 4*, Actaeon Island; 7*, Ile des Phoques; 15*, Swan Island; 16*, Judgement Rocks and South West Island (overlapping sites).

Fig. 9. Results of MDS using recorded and interpolated data on the distribution of reef fishes at the investigated sites. Individual sites are indicated by zone codes (see Fig. 1), with anomalous sites coded using asterisks as in Fig. 8.

Fig. 10. Results of MDS using recorded and interpolated data on the distribution of reef invertebrates at the investigated sites. Individual sites are indicated by zone codes (see Fig. 1), with anomalous sites coded using asterisks as in Fig. 8.

Fig. 11. Results of MDS using recorded and interpolated data on the distribution of reef plants at the investigated sites. Individual sites are indicated by zone codes (see Fig. 1), with anomalous sites coded using asterisks as in Fig. 8.

Fig. 12. Number of recorded and interpolated species (fishes, invertebrates and plants) found on reefs in different areas of the coast out of a total of 195 species on GIS data base.

Fig. 13. Number of recorded and interpolated fish species found on reefs in different areas of the coast out of a total of 78 species on GIS data base.

Fig. 14. Number of recorded and interpolated invertebrate species found on reefs in different areas of the coast out of a total of 40 species on GIS data base.

Fig. 15. Number of recorded and interpolated plant species found on reefs in different areas of the coast out of a total of 77 species on GIS data base.

Fig. 16. Total number of recorded and interpolated fish, invertebrate and plant species found on reefs in different areas of the coast after species recorded during censuses within existing marine reserves had been removed from analysis.

Fig. 17. Degree of similarity in reef biota along different areas of coast, as indicated by DECORANA analysis.

Fig. 18. Locations of major biotic change around the Tasmanian coast, as indicated by Ecotone Analysis.

Fig. 19. Major bioregions inferred for reef biota around the Tasmanian coast, with recommended locations for representative marine reserves also shown. Bioregions are abbreviated by code as follows: Franklin, FRA; Davey, DAV; Bruny, BRU; Freycinet, FRT; Boags, BGS; Otway, OTW; Flinders, FLI; Gippsland, GPS. The central Bass Strait region, an area lacking reefs, is indicated by CBS.